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PRINCIPLES OF SNOW SURVEYING AS APPLIED TO FORECASTING STREAM FLOW[1]

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SNOW SAMPLING

The purpose of snow sampling is to obtain an inelastic standard of measuring snow. The method of "accumulated snowfall", that is, the determination of total depth of newly fallen snow, storm by storm, necessarily involves errors due to variation in density of each snowfall. The average of many years will furnish a fairly accurate normal, but the seasonal measurement may be distorted. Rain gage measurements, even where the catch is reasonably accurate, do not represent the residue of snow or moisture available on March 1 or April 1. Snow stakes do not give the density at all, and even late in the winter after the snow has settled a new storm of fluffy snow may distort considerably the apparent water content of the snow.

APPARATUS[2]

A snow sampler, devised for use on Mount Rose, Nev., has been developed in strength and length to meet all conditions of mountain snow. The entire apparatus, even for the deepest snows, can easily be carried by two persons, and for medium snows can be carried comfortably by one. The basic principle of this sampler is a slotted tube ending in a spiral milled cutter which will cut snow cores however hard the snow may be. A slight offset or shoulder in the inside diameter of the cutter prevents the core from sliding down while being lifted. The slots permit the ready determination of the length of the core and facilitate the cleaning of the tube in case the snow adheres. The upper end of the tube is open, so that by the simple act of inverting, the snow core slides out quickly. Driving and clearing are accelerated by keeping the tube covered with a thin layer of shellac.

The length of the tube depends upon the usual depth of snow found. The measurements are effected by a scale of inches stamped along the length of the tube to measure the depth of the snow and the length of the core, and by a special spring balance by which the net inches of water in the snow sample can be read directly from the dial. Thus no computations are necessary in the field.

The notebook, treated by a special process to withstand snow and water,[3] bears the columns for data essential to making up the forecast (fig. 1).

[1] Received for publication Dec. 10, 1934; issued September 1935.

[2] The description of the apparatus is taken in large part from the following publication: CHURCH, J. E. HUMBOLDT BASIN SNOW SURVEYS AND METEOROLOGICAL DATA. *In* Malone, G. W., Humboldt River Distribution and Different Features Affecting These Deliveries for the Years 1927 to 1931, Inclusive, ch. 5, pp. [87-103], illus. Carson City, Nev. 1932.

[3] The use of waterproof paper for snow surveying was begun by the State of Oregon.

NEVADA COOPERATIVE SNOW SURVEYS

Reno, Nev.

SNOW SURVEY NOTES

Drainage basin _____

Snow course { Name _____
Number _____ Spacing of samples _____

Party chief _____ Date _____, 19__

Number of sample (1)	Depth of snow, inches (2)	Length of core, inches (3)	Water content, inches (4)	Density 100×(4)/(2) percentage (5)	Remarks

N. B.—Sample no. 1 should not be taken at initial point or end of course but one space distant.

Number _____ of _____ sheets. Compiled by _____ Checked by _____.

FIGURE 1.—Form of notebook page on which snow-survey data are recorded.

The average of the total measurements represents the measurement for the course. The density is determined by dividing the water content by the depth. In case too large a proportion of the cores are more than 2 inches short (a condition sometimes caused by sticking snow), the average density is computed only for those measurements where the cores are satisfactory, and this density is applied to the average depth of snow of all the measurements in the course. Thus errors due to the failure of snow to enter the sampler tube can be largely corrected. However, by resampling when the cores are short or by waiting for the snow field to freeze, most of the unsatisfactory measurements can be avoided.

Figure 2 shows the Mount Rose Observatory and the Tahoe Basin; figures 3 to 5 show the snow sampler in use in the field.

RELATIVE VALUE OF DIFFERENT METHODS OF FORECASTING SNOW SURVEYING

Two methods of forecasting based upon snow surveying have been developed—the percentage method and the method of areas. The former method is simple, being merely the determination of the percentage relationship of the seasonal snow cover of any given basin or region to its normal, the assumption being that such a percentage is indicative of the coming seasonal run-off in the streams below. By the latter method the surveyor endeavors to determine the acre-feet of water in the snow fields and the probable net amount that will find its way into the streams.

The difference between the two methods is fundamental. The percentage method is based upon the fact that the big storms which

furnish the bulk of the winter snow are comparatively uniform in intensity over considerable areas, thus lacking the spotted character of the lighter summer rains. Therefore, it is possible to select from

FIGURE 2.—*A*, Mount Rose Observatory at the crest of Mount Rose, elevation 10,800 feet; *B*, view of north and west sides of Tahoe Basin.

4 to 6 snow-survey courses distributed over characteristic parts of a basin and, by averaging their individual seasonal percentages, to obtain a close seasonal percentage for the basin as a whole. The only

requirements are that the snow courses shall be fixed and fairly long, such as 40 measurements 50 to 100 feet apart, and that they be located at a sufficient altitude to prevent distortion of the measurements by winter melting. A safe altitude on the western slope of the Sierra Nevada has been found to be approximately 7,000 feet. However, on the eastern slope and in the Humboldt Range, where the snow at this elevation is shallow, and therefore unstable, a higher elevation should, if possible, be sought. Sites for snow courses should be selected when possible, in protected flats or in timber, where the snow cover does not suffer oscillation from the wind.

The occurrence of early melting in the lower portions of the watershed and consequent distortion in the run-off indicated by the snow survey have caused the development of a zoning system. This

FIGURE 3.—Mount Rose snow sampler; the snow is as deep as the sampler is tall.

system consists of the division of the watershed into a series of altitude zones, measured by a planimeter on a topographic map, with a snow course and normal to represent each. The seasonal percentage for each zone is weighted according to the relative area of each. The average percentage of the zones represents the percentage for the watershed.

The method of areas is beset by two serious difficulties: (1) The large variation in the snow cover (even of individual basins) with elevation and distance from the crest of its watershed: (2) the difficulty of determining the normal seepage and evaporation losses of the region. The close agreement, when the precipitation during the period of run-off is fairly normal, between the snow cover and the run-off as determined by the percentage method is shown in table 1. The apparently wide divergence where the area method is used is shown in table 2.

FIGURE 4.—*A*, Mount Rose snow-sampler cutter; *B*, Mount Rose snow sampler being weighed with its core of snow.

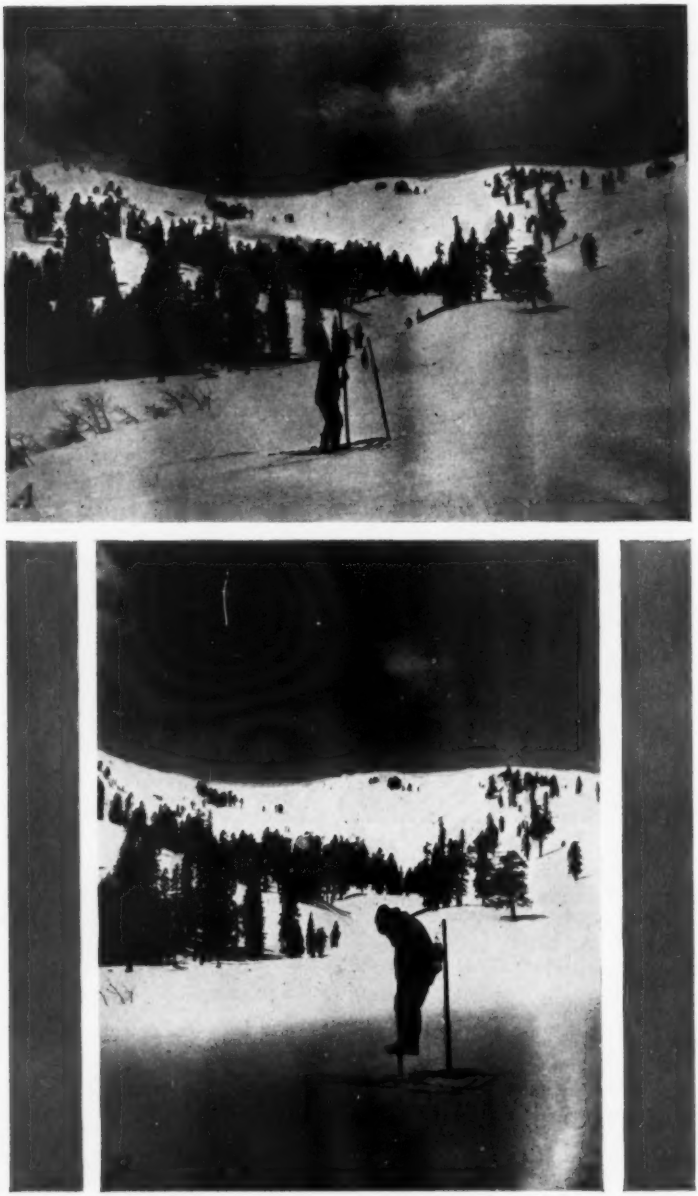

FIGURE 5.—Driving Mount Rose snow sampler (*A*) by hand and (*B*) by using the driving wrench and weight of the body.

TABLE 1.—*Similarity of snow cover in Tahoe Basin as determined by percentage method and rise of Lake Tahoe after Apr. 1, in years of approximately normal precipitation during run-off*

[Percentage of normal]

Item	1910–11	1911–12	1912–13	1913–14	1914–15	1916–17
Snow cover (average of 6 courses)	170.4	49.7	58.2	153.8	88.2	115.6
Actual rise of lake after Apr. 1	172.3	64.5	69.3	150.6	89.8	125.9
Variation between snow cover and run-off	−1.9	−14.8	−11.1	+3.2	−1.6	−10.3

TABLE 2.—*Divergence between method of areas and percentage method of determining rise of Lake Tahoe after Apr. 1 in 1915 and 1916*

Year	Estimated rise by—				Actual rise		Divergence between estimated and actual rise as percentage of normal rise by—	
	Method of areas (corrected for normal losses by evaporation from snow and surface of lake and by absorption by the soil)		Percentage method (no corrections for normal losses necessary)					
	Feet	Percentage of normal	Feet	Percentage of normal	Feet	Percentage of normal	Method of areas	Percentage method
1915	0.08	5.1	1.46	88.2	1.49	89.8	−84.7	−1.6
1916	1.73	104.0	2.52	151.9	[1] 2.48	[1] 149.4	−45.4	+2.5

[1] Corrected by 50 percent for abnormal deficiency in precipitation during rise (see p. 105). Actual rise only 1.65 feet.

METHODS OTHER THAN SNOW SURVEYING

Three methods of forecasting based upon seasonal percentage but not upon snow surveying have entered or may enter into competition with the latter, because of their ease or inexpensiveness. These are the methods of accumulated snowfall, the winter rise of open lakes, and the depth of snow on the ground. The basis for choice between these methods and snow surveying is the degree of accuracy justified by expense.

ACCUMULATED SNOWFALL

An inherent weakness of the method of accumulated snowfall is the variation in the density of the snow, not only from storm to storm but even from season to season. This is particularly true where only the snow stake is employed and the water content of the snow cannot be determined because of distance of station from observer or because of the magnitude of the snowfall. In comparative measurements made in the Tahoe Basin by the Mount Rose Observatory and the United States Weather Bureau the divergence between this method and snow surveying varied between 20 and 55 percent for 5 seasons in a total of 8. Although this method is moderate in cost, its excessive latent inaccuracy makes it undesirable.

WINTER RISE OF OPEN LAKES

The winter rise of lakes (such as Lake Tahoe) which never freeze, should apparently be a safer standard for measuring the snowfall upon the adjacent watershed than the method of accumulated snow-

fall, as the snow falling upon the lake is reduced to water. The reverse is true, however, for the advantage of a fairly inelastic standard, such as water, is overcome by the variable factors of winter run-off from the watershed into the lake and the evaporation from its surface. In fact, a 9-year record shows that with a single exception the method of accumulated snowfall is from 5 to 40 percent more accurate.

Depth of Snow on the Ground

Of the three methods that compete with snow surveying, the depth of snow on the ground at the beginning of the season of run-off is by far the most accurate, and if handled carefully is a close rival of snow surveying. The prime essentials are that courses equal in fixity and length to those used in snow surveying must be maintained and that the measurements of depth must be made only when the new snow has settled approximately to the density of the snow beneath. Fewer measurements, as at occasional snow stakes, or measurements immediately after a storm, would cause corresponding distortion in the results.

Whatever divergence occurs beyond the distortion due to the foregoing factors is caused by the seasonal density attained during the ripening of the snow. This density varies with the winter weather, particularly with temperature and wind, but the maximum variation between seasons is rarely greater than 10 percent. This is shown in table 3, which is based on snow surveys in the Tahoe Basin, in which both the depth of snow on the ground and the water content were determined over the same courses. Since the surveys were made without reference to the date of the previous storm the actual variation between the two methods should be less than that shown in the table.

Table 3.—*Difference between depth of snow on the ground and water content of snow cover in the annual snow survey in Tahoe Basin, Apr. 1, 1909, to 1916*

Method	Seasonal percentage for season indicated						
	1909–10	1910–11	1911–12	1912–13	1913–14	1914–15	1915–16
Depth of snow	80.0	165.1	59.4	66.5	141.9	93.6	145.5
Water content	82.7	170.4	49.7	58.2	153.8	88.2	151.9
Variation	−2.7	−5.3	+9.7	+8.3	−11.9	+5.4	−6.4

The gain over snow surveying is merely in saving the moderate expense for snow samplers. Aside from this the expense for field operations would be identical, without the satisfaction of certainty regarding the data obtained.

VARIABLE FACTORS AFFECTING RUN-OFF

Shrinkage and acceleration of run-off beyond normal occur occasionally, and must be taken into account in predicting the run-off or stream flow of an approaching season.

In forecasting the summer flow from winter snows the chief problem is to anticipate and predict the abnormal shrinkage that infrequently occurs in the seasonal percentage indicated by the April survey. In

the first 11 annual surveys made since 1909 in the Sierra Nevada this shrinkage has occurred to an extreme degree three times and to a moderate degree twice. The maximum shrinkage has been 50 percent of normal for lakes and 25 percent for rivers. Later computations indicate a maximum of 40 and 20 percent respectively.

PRECIPITATION DURING RUN-OFF

The major factor in the phenomenon of shrinkage in the predicted run-off is lack of precipitation during the period of run-off rather than late snowfall or dryness of the watershed. This is plainly indicated by the divergence between the maximum shrinkage in lakes and in rivers. Lakes are susceptible to precipitation in whatever amount, but streams, because of the preponderating land area of their basins, may be from 80 to 90 percent immune to such influence when the soil is driest. In fact, the disparity between the susceptible water areas of lake and river basins, as in the case of Lake Tahoe and the Carson River, may be as great as 50 to 1. When it is considered that evaporation is the complement of precipitation and intensifies its lack, the theoretical probability of apparently so small a cause as lack of late spring and summer rainfall producing so marked an effect on the run-off becomes more understandable. No other weather factors could have caused the divergence. For the Tahoe Basin this precipitation amounts normally to 22.8 percent of the snow cover. In April, when the snow cover is most extensive, it is 10.6 percent, and in May it is 9.5 percent additional.

Despite this fact an effectiveness of 25 percent seems at first anomalous in face of the further fact that occasional summer precipitation in the semiarid West is almost negligible as compared with a field of snow, because of the small proportion of the former that finds its way into the streams. However, at the time when the spring precipitation is heaviest the snow cover is most extensive, coming at times almost as low down as the gaging station, so that whatever precipitation falls at this period finds lodgment upon the snow surface and obtains a relatively untaxed passage to the streams.

As between one region and another, the amount of shrinkage in run-off depends upon the quantitative relationship of the precipitation during run-off to that of the period of accumulation and to the depth of the soil on the watershed. In the Sierra Nevada a deficiency of 100 percent in spring (i. e., April to July) precipitation seems to cause a shrinkage of 16.2 percent of normal in the run-off. However, in the Humboldt Basin in Nevada, where the spring precipitation is relatively four times heavier and the snow survey is made March 1, the shrinkage seems to be more than twice as great, or 36.1 percent. That it is not even greater is possibly due to the greater depth of soil.

In the case of lakes like Tahoe, where the lake surface bears a relationship of 2 : 3 to the land area of the watershed, the shrinkage in expected rise is double that in rivers. These estimates are subject to still further increase owing to increased evaporation attending lack of precipitation, especially when prolonged.

The relation of this fact to the April snow survey may be stated as follows: The equality between the seasonal percentage of the snow field, as measured April 1, and the succeeding run-off of April to July is dependent upon the normality of all factors that influence the run-

off, for the very normal upon which the seasonal percentage is based is merely the average of many seasons, and presumably of so many that any abnormality of the weather has faded into the general average.

MINOR FACTORS REDUCING RUN-OFF

Lack of autumn rains, snowfall less than normal, and shrinkage in run-off below diversion points are contributory but minor factors in the phenomenon of occasional shrinkage of run-off. The absence of autumn rains in the semiarid West seems to have little or no effect upon the amount of moisture necessary to prime the soil in the spring, and its effect even upon the winter run-off is not plainly discernible in the presence of other factors. Indeed, the effect of the heaviest snow covers in the Tahoe Basin, which have a cumulative effect far in excess of rain, does not persist beyond October, or 4 months beyond its peak. This is due to the steep mountain slopes and a surface material sufficiently porous to permit a rapid run-off. Meadows and other retarding media are small in area as compared with the entire watershed, so that even the heavier rains are drained off before the winter has arrived. Moreover, the freezing of the surface soil, so effective on priming in the East, is entirely lacking, for the surface has been drained dry before the freezing temperatures of winter occur.

The effect of subnormal snowfall in reducing the computed seasonal percentage of run-off may be obscured by excess or deficiency of precipitation during run-off, but it can be determined mathematically if the initial factors are known. Since the amount of moisture necessary to prime mountain soil in semiarid regions is practically unaffected by weather, and hence may be considered a fixed quantity for its particular basin, it becomes a factor of increasing importance as the snow cover falls below normal. For example, the normal snow cover of the Tahoe Basin estimated quantitatively by the method of areas is 22.7 inches water content and the amount of absorption in priming the soil theoretically determined is 8.6 inches, or 37.9 percent. This factor of absorption was obtained in the following manner. The actual mean rise of the lake to April 1 was 1.46 feet, and the mean rise after April 1 was 1.66 feet. Since the rise to April 1 is due largely to precipitation on the surface of the lake, it is safe to assume a precipitation fully as great, and apparently 1.76 times greater on the land area that drains into it, judging from the relation of the precipitation around the edge of the lake to the average precipitation over the slopes above it (based on the relationship of 176.1 percent between the snow at Ward Creek, elevation 7,000 feet, and Tahoe city). Furthermore, the land area is 1.5 times larger than the water surface, or, more exactly, 306.9 square miles to 192.7 square miles, thus making a total preponderance of 2.6 times. Therefore, if there were no accretions from the watershed and no losses through evaporation, the absorption would be determined thus:

$(1.76 \times 306.9) : 192.7 ::$ estimated mean rise :	1.46 feet.
Estimated mean rise after April 1 due to melting snow (uncorrected for absorption)	4.09 feet.
Actual mean rise	1.66 feet.
Mean absorption	2.43 feet = 59.4 percent.

However, on the basis of the flow of the neighboring West Fork of the Carson River above 5,600 feet, approximately 15 percent of the rise before April 1 can be attributed to run-off during the winter from the watershed, leaving 1.24 feet as the rise due to direct precipitation on the lake. On the other hand, the winter run-off causes some loss of snow on the watershed. At the ratio of 2.64 (relative precipitation and area) to 1, this would amount, if distributed over the watershed, to 5.7 percent, which should be still further decreased because the winter run-off is fed in part by autumn rains. Consequently, this loss may be regarded as negligible.

Again, since the water of the lake evaporates more rapidly than the snow on the watershed, a further correction should be applied to the lake level to restore the balance. For this an approximate factor of 3.5 inches or 0.29 foot is proposed for the period preceding April 1, and the same or a slightly larger factor for the period following it.

The actual mean rise of the lake to April 1, as thus corrected for difference in evaporation, would be 1.53 feet (=1.24+0.29), and the rise or run-off after April 1, 1.95 feet (=1.66+0.29). The absorption would then appear thus:

(1.76×306.9) : 192.7 :: estimated mean rise : 1.53 feet.	
Estimated mean rise (corrected for difference in evaporation but uncorrected for absorption)	4.29 feet.
Mean actual rise (corrected for evaporation)	1.95 feet.
Mean absorption	2.34 feet=54.5 percent.

The quantitative determination of the absorption is more difficult because of the lack of a quantitative normal for the watershed. However, the unexpectedly close agreement between the trial normals for 1914–15 and 1915–16, the years under discussion, computed on the basis of the individual seasonal percentage of each, encourages their adoption as a satisfactory joint substitute. Table 4 gives the details.

TABLE 4.—*Forming a quantitative normal from seasonal percentage*

Year	Average water content of snow cover	Seasonal percentage of snow cover	Quantitative normal for snow cover
	Inches		*Inches*
1914–15	19.93	88.2	22.60
1915–16	34.66	151.9	22.81
Quantitative normal of snow field			22.71

On the basis of the foregoing quantitative normal, the mean quantitative absorption, 54.5 percent of the snow field, amounts to 12.38 inches. However, since one-third of this amount has already entered the soil, especially on the lower levels, by April 1, when the survey is made, the net mean absorption is estimated at only two-thirds of the foregoing amount, or 8.25 inches.

The decrease in run-off with decrease in seasonal percentage of snow for the Tahoe Basin is shown in table 5.

TABLE 5.—*Decrease in run-off with decrease in seasonal percentage of snow for Tahoe Basin*

Snow cover		Absorption	Run-off		Decrease from snow cover of normal run-off
Percent	*Inches*	*Inches*	*Inches*	*Percent*	*Percent*
100 [1]	22.7	8.6	14.1	100	.0
75	17.0	8.6	8.4	59.5	15.5
50	11.4	8.6	2.8	19.9	30.1
25	5.7	8.6	[2] −2.9	[2] −20.5	[2] −45.5

[1] Normal.
[2] The minus sign indicates the entire absence of run-off, and the figures 2.9, 20.5, and 45.5 indicate the amount of deficiency.

Shrinkage in the expected flow below diversions is similar in effect to subnormal snow, for not only is the ratio of decrease progressive, but the land is thirstier because of the general dryness of the season. In years of heavy precipitation the diversions tend to increase the seasonal percentage, as based upon the snow fields. One of the observations made in 1919–20 is shown in Table 6.

TABLE 6.—*Shrinkage in expected run-off below diversions for Carson Basin with Tahoe and West Walker Basins as checks; April–July 1920*

Basin	Expected run-off			Diversions	Actual run-off		Diminution from normal
	Normal	Seasonal 1919–20			Amount	Percentage of normal	
	Acre-feet	*Percent*	*Acre-feet*	*Acres*	*Acre-feet*		*Percent*
Carson (Empire)	246,412	70.0	172,488	27,000	97,496	39.6	30.4
Tahoe	[1] 1.66	50.2	[1] 0.83	None	[1] 0.89	53.6	3.4
West Walker	190,366	74.8	142,394	Small	164,100	66.2	11.4

[1] Rise.

This shrinkage is shown conspicuously in the variation in the ratio of the use of water in the Truckee Meadows with variations above and below normal in the stream. These meadows consist of approximately 35,000 acres of irrigated and swamp land around Reno, Nev., supplied by a normal April to July run-off of 350,000 acre-feet. During the 12 years from 1908 to 1919, the average variation at the gaging stations above and below all diversions in the Truckee River, which is the main source of supply, was as follows: (1) With run-off above normal, +8,676 acre-feet; (2) at normal, −2,668 acre-feet; (3) below normal, −55,760 acre-feet. In terms of the normal run-off of this river the percentage of variation is +2.7 when the stream is above normal; −0.8 percent when at normal; and −17.1 percent when below normal. The data are shown in table 7.[4]

[4] NORCROSS, C. A. WATER COST OF IRRIGATION, TRUCKEE VALLEY, NEVADA. Nev. Agr. Col. Ext. Bull. 25:16. 1919.

TABLE 7.—*Effect of diversions in Truckee Basin, Nev., April–July*

[Normal run-offs, 325,745 acre-feet [1]]

Year	Snow cover percentage of normal	Run-off in acre-feet			
		At State line (above diversions)	At Vista (below diversions)	Average variations	
				Amount	Percentage of normal
	Percent	*Acre-feet*	*Acre-feet*	*Acre-feet*	
SEASONS ABOVE NORMAL RUN-OFF					
1908–9	[2]	600,200	582,900		
1910–11	176.4	789,000	799,000		
1913–14	142.1	544,442	622,540		
1915–16	148.9	473,850	452,780		
1916–17	118.9	449,510	443,160		
Average		571,400	580,076	+8,676	+2.7
SEASONS OF NORMAL RUN-OFF					
1909–10	76.7	308,400	337,700		
1914–15	83.2	341,650	361,870		
1918–19	88.1	349,818	292,294		
Average		333,289	330,621	−2,668	−0.8
SEASONS BELOW NORMAL RUN-OFF					
1907–8	[2]	231,800	164,900		
1911–12	48.5	200,400	136,300		
1912–13	52.9	215,590	175,700		
1917–18	[3] 89.6	253,548	201,400		
Average		225,335	169,575	−55,760	−17.1

[1] Additional run-off from creeks flowing directly into the Truckee Meadows 22,000 acre-feet (estimated).
[2] Previous to establishment of snow survey.
[3] Though snow cover was nearly normal, the precipitation during run-off was deficient 63 percent.

The failure of the ratio to rise in seasons above normal as much as it falls in seasons below normal is evidently due to the relatively small draft made by the meadows upon the waters of the Truckee and auxiliary creeks, even when the stream is only at normal. Discrepancies in individual seasons, as in 1918–19, are rare and may be due to other factors, such as previous condition of soil moisture or variations in rate of evaporation.

Most of the factors mentioned in the foregoing discussion are illustrated in table 8, based upon 4 seasons of deficient precipitation during run-off, with 6 check seasons of normal spring and summer rainfall. A lake and a river basin adjoining each other, and consequently exposed to similar weather conditions, are selected to show the divergence between the types.

The dominant and consistent correlation is the precipitation, the river basin being less affected by extremes than the lake basin. The priming of the soil by autumn rains or winter run-off presents constant contradictions. The effect of the extremely subnormal years of 1911–12 and 1912–13 is obscured by excess precipitation, and shrinkage below diversions during these years does not appear, possibly also because of the summer rainfall. The data in this table are con-

firmed by those obtained in the season of 1919-20, immediately following, in which the forecast for was approximately 20 percent below normal, and the summer rains, except for two heavy showers, were entirely lacking. The diminution in run-off seems to have been as high as 30 percent.

TABLE 8.—*Effect of weather upon seasonal run-off in seasons with and without abnormal shrinkage in run-off in Carson River and Tahoe Lake Basins.*

SEASONS OF ABNORMAL SHRINKAGE IN RUN-OFF (PERCENTAGE OF NORMAL) CARSON RIVER BASIN

Year	Water content of snow cover	Priming of soil as shown by excess and deficiency of autumn rains and winter run-off.		Excess and deficiency of precipitation and evaporation.		Run-off	
		Autumn rains	Winter run-off	Precipitation	Evaporation	Seasonal percentage	Variation between snow cover and run-off
1909–10	[1] 82.7	+165.41	+38.31	−29.2		64.14	−18.6
1915–16	[1] 151.9	−60.55	+49.59	−70.4		125.71	−26.2
1917–18	96.4	−25.19	−29.51	−57.2	[2] +27.7	[3] 61.31	[3] −35.1
1918–19	96.8	+100.00	−44.52	−0.8	[2] +36.2	66.58	−30.2

SEASONS OF ABNORMAL SHRINKAGE IN RUN-OFF (PERCENTAGE OF NORMAL) TAHOE LAKE BASIN

1909–10	[1] 82.7	+140.18	[4] +38.31	−86.9		61.45	−21.2
1915–16	151.9	−42.83	[4] +49.59	−82.9		99.40	−52.5
1917–18	95.0	−71.96	[4] −29.51	−63.0	+27.7	53.61	−41.4
1918–19	103.0	+113.69	[4] −44.52	−63.5	+36.2	[5] 72.89	[5] −30.1

SEASONS WITHOUT ABNORMAL SHRINKAGE IN RUN-OFF (PERCENTAGE OF NORMAL) CARSON RIVER BASIN

1910–11	[1] 170.4	−18.80	+7.36	+26.8		176.70	+6.3
1911–12	[1] 49.7	−40.98	−40.75	+51.0		42.43	−7.3
1912–13	[1] 58.2	+22.18	−57.30	+72.4		57.18	−1.0
1913–14	[1] 153.8	−16.92	+81.89	+3.5		162.95	+9.2
1914–15	[1] 88.2	−48.50	−17.35	−.4		93.33	+5.1
1916–17	[1] 115.6	+30.08	+19.08	+.4	[2] +6.0	128.65	+13.1

SEASONS WITHOUT ABNORMAL SHRINKAGE IN RUN-OFF (PERCENTAGE OF NORMAL) TAHOE LAKE BASIN

1910–11	170.4	−12.80	[4] +7.36	+3.27		172.29	+1.9
1911–12	49.7	−60.26	[4] −40.75	+63.48		64.46	+14.8
1912–13	58.2	+27.15	[4] −57.30	+12.59		69.28	+11.1
1913–14	153.8	−6.80	[4] +81.89	−4.53		150.60	−3.2
1914–15	88.2	−56.73	[4] −17.35	+11.84		89.76	+1.6
1916–17	115.6	−13.02	[4] +19.08	−23.43	[2] +6.0	125.90	+10.3

[1] Substituted from Tahoe Basin because of lack of snow surveys.
[2] From floating pan at Tahoe City.
[3] At Clifton, 20 miles below Empire. Probable correction 5 percent; seasonal 66.31 and variation 30.1.
[4] Interpolated from Carson River.
[5] Maximum rise accelerated 3 weeks by high temperature. If corrected for evaporation to normal date of maximum elevation, July 7, seasonal percentage of run-off would be 60.89 and variation 42.1.

APRIL PRECIPITATION

The precipitation factor in table 8 is made more obvious by the preponderance of the April or April-May precipitation over the remaining precipitation in the seasons of 1913–14, 1914–15, and 1916–17. Thus, in the Tahoe Basin in 1913–14, nearly two-thirds of the total precipitation during run-off fell in April; in 1916–17, more than

two-thirds; and in 1914–15, although only 0.54 inch fell in April, this was supplemented in May by 3.70 inches, the joint precipitation amounting to ninety-five one hundredths of the total for the run-off period.

In the Tahoe Basin the normal April precipitation (1.78 inches) is estimated at 10.6 percent and the May precipitation (1.60 inches) at 9.5 percent of the normal winter snow cover, while the precipitation for June is only 2.7 percent and that for July 1 to 15 is negligible. Thus, in view of the continuous melting of the snow fields after March 15 and the increasing area of exposed soil, the precipitation for April should indicate the probability of normality or shrinkage in the seasonal run-off. It is possible, however, that the May precipitation at times may become the deciding factor, or that concentrated rain, as in 1919–20 may complete the monthly or seasonal normal and leave bright skies to accelerate the evaporation. But this latter effect is only partial as compared with total lack of rain.

ACCELERATION OF RUN-OFF

Acceleration or even retardation of snow melting does not necessarily mean abnormal increase or decrease in the relative seasonal run-off, for the melting when once begun is almost continuous. Consequently, the soil has no opportunity to dry out, and the total variation in run-off is probably less than 8 percent.

It is a striking fact that in all of the seasons of abnormal shrinkage in run-off shown in table 8 the seasonal temperature during run-off was from 0.7° to 4.2° F. in excess of normal. This temperature was 2.5°, 0.7°, 3.0°, and 4.2° F. in excess for the seasons of 1909–10, 1915–16, 1917–18, and 1918–19, respectively. Its principal effect was to run the moisture from the snow fields prematurely, without noticeably increasing the total seasonal flow. The percentage of normal run-off in the Carson Basin in 1918–19 was as follows: April, 86.4; May, 115.2; June, 27.6; July, 4; April–July, 58.3. The excess in temperature at Reno, Nev., during April was 2.1°; May, 7.2°; June, 1.8°; July, 5.7°; April–July, 4.2° F. The percentage of normal snow cover on April 1 was 98.6 and the variation between run-off and snow cover 30.2 percent below normal.

Although the May flow is 16.6 percent above that of the snow cover, the June flow falls to a deficiency of 71 percent, while the July flow is negligible. The total seasonal loss of 30.2 percent, due to lack of rains, is so large that little compensation can have come from the accelerated melting, but it is possible that the increased ratio of shrinkage below diversions accompanying subnormal run-off may have clouded the result.

LIGHT DENSITY OF LATE SNOWS

That late mountain snows have a tendency to run off prematurely is not proved by data so far gathered. The fact is rather that these snows pass through a process of accelerated ripening as a result of the alternation of thawing and freezing that occurs normally in April above the elevation of 7,000 feet. For example, at Summit Station, Calif., in 1917–18, the relative density of the snow field for its entire depth was only 36.6 percent on March 24, but on April 15 it had increased to 49.2 percent with a loss of only 3.3 inches above the current precipitation in a total snow cover of 32.8 inches.

It is true that snow of light density at the beginning of the time of melting, before losing its water, fails to attain the density of snow of higher initial density. But the maximum seasonal variation in density for the Tahoe Basin as a whole is under 13 percent, and no marked effect from light densities appears in the run-off. This is shown in table 9 by the lack of correlation between deficiency in density [5] and the advancement of the month of maximum run-off or even of acceleration in the melting, which latter is due mainly to excess of temperature.

TABLE 9.—*Lack of correlation between light density of snow cover and early maximum run-off in Carson River Basin, 1909–10 to 1915–16*

Year	Snow cover in Tahoe Basin (percentage of normal)	Excess or deficiency in density of snow	Excess or deficiency in temperature from March to month of maximum acceleration inclusive	Month of maximum run-off (normal month, May)	Percentage of monthly normal run-off to show acceleration [1]					
					March	April	May	June	July	August
		Percent	°*F*							
1909–10	83.3	+3.3	+7.5	May	**134.43**	**127.66**	74.54	34.18	19.01	
1910–11	167.5	+2.4	+.7	June	142.01	135.63	113.05	**236.24**	**258.36**	161.10
1911–12	49.9	−9.5	−1.2	do	37.0	7.62	52.78	**61.83**	12.61	
1912–13	58.3	−8.2	+.6	May	44.35	57.09	**92.35**	36.26	14.0	
1913–14	154.1	+12.2	+4.2	do	162.10	163.29	**178.65**	148.95	156.06	141.37
1914–15	88.4	−5.2	+2.0	June	71.40	95.23	83.11	108.69	77.16	
1915–16	152.2	+6.7	+4.4	May	134.39	161.95	121.58	118.52	101.40	

[1] Maximum accelerations shown in bold-faced type.

CHARACTER OF STREAM BED

An exception to the foregoing statements must be made in the case of the Humboldt Basin. Owing to the alluvial character of the stream bed and obstructions in the channel, an unusual amount of water is required for priming the river. This amount becomes excessive when the stream bed has become dry because of a preceding dry year. As high as 20 percent of the normal run-off has been required for such priming, and in 1931–32 a correction of 30 percent was made for superdryness resulting from a succession of dry years. In the Humboldt Basin this factor is next in importance to precipitation during run-off.

PREDICTING RUN-OFF FROM LARGE AREAS

UNIFORMITY IN THE SNOW COVER

Uniformity of the snow cover in adjoining basins is an important feature in making practicable the forecasting of run-off from large areas. This condition of uniformity is due to the fact that winter storms which build the snow cover on the mountains are usually wide-spread in their sweep and that the gradient of their intensity is

[5] See column 3, table 9.

low and uniform for relatively wide distances. This is particularly true of the "big storms" that often furnish the bulk of the winter precipitation. However, in seasons of heaviest snow cover, the oscillation or variation between basins (as shown by river flow in table 10) appears at times, but not uniformly, to be more accentuated than in seasons of normal or light snow cover.

The similarity of snow cover in adjoining basins is indicated distinctly by the snow surveys of 1917–20, as shown in table 10; yet the last two basins, Carson and Walker, cover a joint distance of 95 miles.

The gradient of seasonal percentage increased toward the south in 1917–18 and 1919–20, but toward the north in the intervening year. This uniformity is not a local peculiarity, but has been found also in the Wasatch Range, Utah. For example, the snow surveys of 1913–16 in the City Canyon and Big Cottonwood Canyon Creeks, conducted by the United States Weather Bureau and the engineering department of Salt Lake City, respectively, varied from each other during the entire period only 1.7 and 2.9 in seasonal percentage. The distance between these basins is 14 miles.

TABLE 10.—*Similarity of seasonal percentage of snow cover in adjoining basins 1917–18 to 1919–20*

Season	Percentage of snow cover in indicated basins, each being represented by 1 central station			
	Yuba (Summit station)	Tahoe (Rubicon Peak)	Carson (Blue Lakes)	Walker (Center Mountain)
1917–18	82.5	90.6	96.4	
1918–19	107.1	[1] 95.5	96.8	97.0
1919–20	71.6	73.3	75.3	88.2

[1] The average of the 3 crest stations, Ward Creek, Rubicon Peak, and Lake Lucile, is 104.7.

CONDITIONS IN THE SIERRA NEVADA RANGE

To extend the study of uniformity of the snow cover beyond the present limit of the snow surveys, provisional recourse has been had to the run-off of such streams in the Sierra Nevada as were obviously dependent upon the snow cover. To reduce the streams to a common standard, the seasonal percentage of each in terms of its own normal was taken. Furthermore, to avoid all possible influences except that of the snow, the normals and seasonal percentages were confined to April–July. Finally, the streams were grouped laterally and transversely along the range to determine the probable amount of oscillation in the snow and the detailed snow surveys necessary to detect it.

Table 11 includes particularly the division by slopes. The western slope is fully represented from the Klamath to the Kern. The eastern slope still lacks the minor basins of Honey Lake and Goose Lake in the north, for which no data are available. The foothill streams, being fed only to a minor extent by snow, are segregated from the rest. The primary peak of their flow occurs in midwinter, and only occasionally does their April–July run-off correspond closely with that that of the crest streams.

If the run-off of the 15 crest streams on the western slope were represented graphically, there would be a curve varying from end to end annually from 24.9 to 299.4 percent. The latter represents the season of 1915–16, when the apparent snow cover increased from 98.3 percent in the upper Klamath Basin at the northern end of the range to 390.3 percent in the Kern Basin at the far southern end, and disastrous floods occurred even at San Diego.

If the slope is divided into three sections of approximately 150 miles each, the extreme annual variation in each would be somewhat reduced: Northern Sierra section, 8.6 to 91.4 percent; central Sierra 11.1 to 49.4 percent; southern Sierra, 9.7 to 259.0 percent, the latter occurring the year of the flood. If the upper Sacramento-McCloud and Kern Basins, situated at the extreme ends of the range, are treated as parts of new sections, the variations in the plateau section should be reduced to the extremes of 6.1 and 27.4 percent and in the southern Sierra sections to 2 and 57.9 percent. Finally, and of greatest importance for forecasting, the individual percentages for several adjoining basins represent, with occasional exceptions, a fairly uniform curve of change, not only within the several sections but also overlapping from one section to another.

Even closer uniformity exists on the eastern slope, if the rise of Lake Tahoe is corrected for excess and deficiency of precipitation upon its surface to make the run-off in its lake basin more comparable to that in river basins. The variation might be even smaller if corrections were made for evaporation and diversion of water in the Tahoe and Carson Basins respectively.

Likewise, if a cross section of the two slopes is taken, a similar uniformity in the snow fields, with occasional variation, is shown by the streams that head in a common summit but flow down the range in opposite directions. Unfortunately, all examples are confined as yet to the northern Sierra section. In the Truckee-Yuba Basins the extremes in annual variation are 3.7 and 36.1 percent; in the Tahoe-American 0.3 and 42.4 percent; in the Carson-Mokelumne Basins, 2.3 and 49.2 percent; and in the West Walker-Tuolumne Basins, 0.1 and 20.1 percent. In this last case, data are lacking for the year of probably maximum variation. Table 12 furnishes details of the records.

TABLE 11.—*Variations in percentage of normal run-off, April–July period, 1909–10 to 1918–19 between streams [1] on the same slope of the Sierra Nevada*

Side and section of range and total length	Basin	1909–10	1910–11	1911–12	1912–13	1913–14	1914–15	1915–16	1916–17	1917–18	1918–19
East side:											
Central Sierra (110 miles)	Tahoe [2]	73.85	172.29	55.76	67.68	151.60	88.76	111.20	127.40	62.61	81.99
	Carson	64.14	176.70	42.43	57.18	162.95	93.33	125.71	128.65	[3] 61.31	66.58
	West Walker	96.57	150.58	56.23	50.96	----	----	119.98	106.85	81.95	70.34
	Maximum variation	**32.4**	**26.1**	**13.8**	**16.7**	**11.4**	**4.6**	**14.5**	**21.8**	**20.6**	**15.4**
Southern Sierra (65 miles to gaging station)	Owens	92.8	141.8	61.5	61.9	143.7	86.0	99.3	117.5	73.1	----
Maximum variation of east side		**32.4**	**34.9**	**19.1**	**16.7**	**19.3**	**7.3**	**26.4**	**21.8**	**20.6**	----
West side (505 miles):											
Northern Sierra (approximately 120 miles)	Sacramento	71.0	112.2	80.2	79.0	115.8	141.3	81.5	91.0	53.0	69.8
	Feather	60.7	183.7	46.2	69.2	123.5	139.5	115.7	114.1	47.0	72.8
	Maximum variation	**10.3**	**71.5**	**34.0**	**9.8**	**7.7**	**1.8**	**34.2**	**23.1**	**6.0**	**3.0**
Central Sierra (approximately 210 miles)	Yuba	66.67	146.10	56.58	68.10	112.61	117.27	111.87	104.93	47.67	70.82
	American	77.58	184.12	56.20	60.13	109.25	124.04	110.88	110.10	53.46	76.85
	Mokelumne	79.95	168.22	53.24	51.84	113.75	109.01	109.35	113.54	63.64	75.29
	Stanislaus	74.31	163.92	49.80	44.14	105.16	105.46	110.32	109.74	60.65	61.09
	Tuolumne	76.49	150.66	59.82	59.49	113.17	105.65	102.33	107.95	73.12	67.21
	Maximum variation	**13.3**	**38.0**	**10.0**	**24.0**	**8.0**	**18.6**	**9.5**	**8.6**	**25.5**	**15.8**
Southern Sierra (approximately 175 miles)	Merced	----	----	54.6	47.7	118.7	90.1	127.4	103.0	77.7	71.2
	San Joaquin	82.4	176.1	55.1	42.7	136.9	104.2	131.3	97.2	76.4	60.1
	Kings	78.8	142.3	52.8	49.7	123.8	101.7	150.1	97.5	77.2	60.2
	Kaweah	50.0	116.4	53.1	53.9	98.3	95.8	151.3	105.8	55.1	66.0
	Kern	87.6	174.1	62.5	52.6	170.3	113.0	390.3	139.1	83.1	76.5
	Maximum variation	**37.6**	**57.9**	**9.7**	**11.2**	**72.0**	**17.2**	**259.0**	**41.9**	**28.0**	**16.4**
	Maximum variation exclusive of Kern.	**32.4**	**57.9**	**2.0**	**11.2**	**38.6**	**8.4**	**20.0**	**8.6**	**23.1**	**5.9**
Maximum variation of west side		**37.6**	**71.9**	**34.0**	**36.3**	**72.0**	**45.5**	**177.5**	**48.1**	**36.1**	**16.8**
Foothill streams, west side:											
Central Sierra	Cosumnes	77.23	218.65	62.88	57.24	91.34	153.42	114.48	142.02	64.72	72.0
Southern Sierra	Tule	58.7	112.8	63.2	37.7	95.5	154.3	207.3	147.8	36.2	65.8

[1] These streams are also assembled in groups and the maximum variation within each group is given, likewise the maximum variation for the slope as a whole.
[2] The rise of Tahoe has been corrected for excess or deficiency of precipitation upon its surface to make its rise more comparable with the run-off of the streams.
[3] At Clifton, 21 miles below Empire, where measurements are usually taken. Correction for diversion should probably be +5 percent.

TABLE 12.—*Variation between run-off of streams on opposite slopes of Sierra Nevada that have a common summit, for April-July periods, 1909–10 to 1918–19*

Section	Basin	Percentage of normal run-off for years indicated									
		1909–10	1910–11	1911–12	1912–13	1913–14	1914–15	1915–16	1916–17	1917–18	1918–19
North	Tahoe [1]	73.85	172.29	55.76	67.68	151.60	88.76	111.20	127.40	62.61	81.99
	Yuba	66.67	146.10	56.58	68.10	112.61	117.27	111.87	104.93	47.67	70.82
	American	77.58	184.12	56.20	60.13	109.25	124.04	110.88	110.10	53.46	76.85
	Maximum variation [2]	**7.2**	**26.2**	**.8**	**7.6**	**42.4**	**35.3**	**.3**	**22.5**	**14.9**	**11.2**
Middle	Carson	64.14	176.70	42.43	57.18	162.95	93.33	125.71	128.65	[3] 61.31	66.58
	Mokelumne	79.95	168.22	53.24	51.84	113.75	109.01	123.28	113.54	63.64	75.29
	Stanislaus	74.31	163.92	49.80	44.14	105.16	105.46	110.32	109.74	60.65	61.09
	Maximum variation. [2]	**15.8**	**12.8**	**10.8**	**13.0**	**57.8**	**15.7**	**15.4**	**18.9**	**2.3**	**14.2**
South	West Walker	96.57	150.58	56.23	50.96	.....	.....	119.98	106.85	81.95	70.34
	Tuolumne	76.49	150.66	59.82	59.49	113.17	105.65	102.33	107.95	73.12	67.21
	Maximum variation. [2]	**20.1**	**.1**	**3.6**	**8.5**	.....	.....	**6.7**	**1.1**	**8.8**	**3.1**

[1] Corrected for rainfall on surface of the lake.
[2] Bold-faced figures indicate variation between slopes.
[3] At Clifton, 20 miles below Empire, where measurements are usually taken; correction for diversion should probably be +5.0 percent.

OSCILLATION IN THE SNOW COVER

The second marked characteristic of the snow cover, as shown by the flow of the streams (table 11), is its occasional heavy oscillation along or across the range. A striking illustration of the former is the continuous and frequent zigzag in the seasonal percentage between the basins along the western side of the Sierra Nevada proper in 1910–11, when the maximum variation even within the individual sections was at its peak of 38.0 to 57.9 percent. Another illustration is the sudden upward sweep in the Kern Basin of 72 percent from the neighboring Kaweah Basin in 1913–14 and 239 percent in 1915–16.

Oscillation across the range is illustrated by the diversity in the stream flow in the northern Sierra section in 1913–14 (table 12). Although the maximum oscillation along the range, as measured on the western side, was only 18.3 percent, the oscillation across the axis in the four several groups of basins varied from 28.5 to 49.2 percent, the excess being uniformly on the eastern side.

QUADRANGLES IN FORECASTING

On the basis of stream flow, both uniformity and oscillation over the range can be detected and forecasted most accurately by dividing the range into a series of sections or quadrangles, the length of each according, theoretically, with the length of oscillation (fig. 6). But, practically, the quadrangle should be short enough to keep the normal oscillation within reasonable limits without regard to any overstepping from one section to the other. The width of the quadrangle should be sufficient to include all foothills above the elevation of 6,000 to 8,000 feet on both sides of the crest, in order to furnish as long a transverse base line as possible. Crest stations with outposts on both sides should be maintained to reveal any deviation in the seasonal percentage either along or across the range. Each basin should be represented by one or more crest stations, the number depending upon the size of the basin or the reliability of the station.

In the original California-Nevada cooperative snow survey, three quadrangles were tentatively formed. The oldest was the central Sierra quadrangle, comprising the Honey, Tahoe, Carson, and Walker Basins on the eastern slope, and the Feather, Yuba, American, Moke-

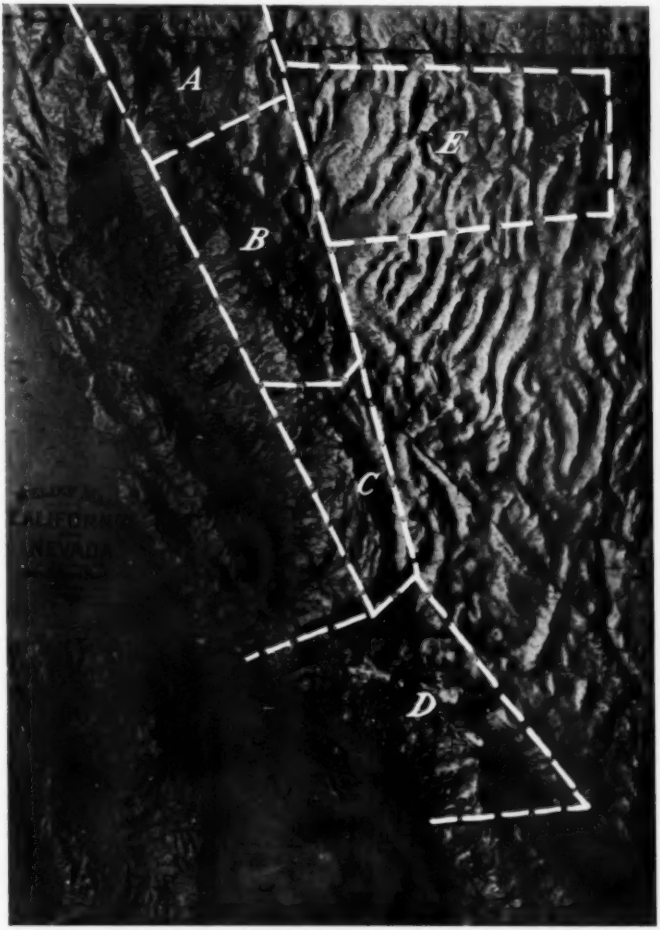

FIGURE 6.—Relief map of California and Nevada with quadrangles showing longest feasible units for forecasting stream flow in Sierra Nevada and Great Basin ranges: *A*, northern Sierra quadrangle; *B*, central Sierra quadrangle; *C*, southern Sierra quadrangle; *D*, Southern California quadrangle; *E*, Humboldt quadrangle.

lumne, Stanislaus, Tuolumne, and Merced Basins on the western slope. Crest stations representative of the major portion of the quadrangle were established, with outposts along the eastern side, four of the latter being on the crest of the Carson Range, which forms the eastern wall of the Tahoe Basin. On the western side, outpost stations

were established only in the Yuba Basin in the northwestern part of the quadrangle.

The southern Sierra quadrangle included all crest basins from the San Joaquin Basin to Tehachapi Pass, thus comprising the San Joaquin, Kings, Kaweah, and Kern Basins on the west and the long Owens Basin on the east. Special attention should be given to the surveys in the complex Kern Basin, which includes the long trough between the double crest of the high Sierra and the broad valley adjoining the Mojave Desert. The northern Sierra quadrangle comprised the upper Klamath, McCloud, Pit, and upper Sacramento Basins on the west and the minor Goose Lake Basin on the east. The mountains are relatively low and without commanding crests, and outpost stations are difficult to obtain. Moreover, the maximum flow of the streams occurs in February to May, instead of March to June and April to July as do the streams successively toward the south, but the curve of flow is greatly flattened by the retarding effect of the lava field. However, the snow fields of Mount Shasta and Lassen peak, aided by seasonal catch gages on the floor of the basin, might prove to be a factor of considerable importance in helping to forecast the flow.

Foothill Streams and Southern California

The Cosumnes and Tule, the only foothill streams of major importance in the Sierra, resemble the northern Sierra streams in their early run-off. However, their curve of flow is sharper and the necessity of early surveys and short forecasts is consequently greater. The western outpost station of the Mokelumne at Bear River Reservoir would serve as a crest station for the Cosumnes; and Hackett Meadows, selected as one of the western outposts for the Kaweah-Tule, would serve reasonably well as a crest station for the Tule. The only possible outpost stations for either would be precipitation stations equipped with catch gages.

In southern California, where the ranges are comparatively low and the precipitation is light, many of the crest stations must depend upon catch gages for determining the total winter precipitation, and except in the case of underground flow, the forecast must often present the effect of individual storms, rather than the cumulative effect of the entire season. However, the presence of some high peaks, as in the San Gabriel Mountains, and the major importance of the subsurface flow make the establishment of a fourth quadrangle, known as the Southern California quadrangle, desirable.

In this quadrangle the seasonal water must be classified under two heads: (1) The amount available from snow fields and the precipitation that falls upon them, and (2) the amount available from rain or quickly melting snow. Since the priming loss from the first is far less than from the second, it follows that the net gain from the former is far greater and should be given greater weight in estimating water resources.

The net gain from the latter will naturally depend upon the heaviness of the precipitation and the previous dryness of the soil. The foregoing general plan is being carried out by the present California cooperative snow survey except that the local basin rather than the quadrangle constitutes the main unit.

INAUGURATING A SNOW SURVEY

LOCATING THE SNOW-SURVEY COURSES

In inaugurating the snow survey of a basin or drainage area, the initial steps should be to determine the chief tributaries of the draining stream and to locate snow-survey courses at points of major flow. In this way a large basin can be served with a minimum of effort. For example, the Humboldt Basin in Nevada (fig. 6) has a length of 350 miles and a drainage area of 14,200 square miles above Humboldt Lake, which receives its residual waters. But its run-off can be determined fairly well from four stations strategically placed in the Ruby and Charleston-Independence Mountains, these being parallel ranges 80 miles apart which furnish approximately 90 percent of the water of this basin.

The supplies from these two ranges bear approximately the ratio of 3.2 in favor of the higher and more rugged Ruby Range. Of the

FIGURE 7.—Ideal site for a snow course, Big Meadows, eastern outpost snow course of the Truckee River basin. (Meadow is in middle distance.)

feeders from the Charleston-Independence Ranges, Mary's River and North Fork furnish 84 percent of the total run-off on that side, and of the three from the Ruby Mountains, Lamoille Creek and South Fork furnish 86 percent from their group. Furthermore, South Fork furnishes twice as much water as Lamoille Creek. On the basis of these observations, there should be 4 groups of snow courses: 2 in the Ruby Range, 1 each along South Fork and Lamoille Creek, and 2 in the Charleston-Independence Ranges, along the headwaters of Mary's River and North Fork. The courses planned for the larger streams in each group will serve probably for the smaller streams as well. An ideal course site is shown in figure 7.

An exampie of another type is the Bow River Basin of Alberta, Canada, where the Canadian Meteorological Service inaugurated snow surveys in 1916–17. This basin is so alpine at its head in the Glacier National Park that a survey by the method of areas is physically impossible, and even a survey by the method of seasonal percentage is far from easy because of the difficulty of finding sites for stable courses. But an adjacent smaller basin of gentler contours has a

snow cover closely representative of that in the larger basin. Consequently, the seasonal percentages in the smaller basin can be safely applied to the stream flow of the Bow River Basin also.

In basins reaching far down from the crest of the range, crest and outpost stations should be established, the latter at a sufficient distance from the former to give a fair average of seasonal percentage at the two extremes of the basins.

Zoning

Recent years of light precipitation and premature melting have driven forecasters inevitably to zoning. The outposts which seemed to provide an index of oscillation horizontally furnished no clue vertically even when early run-off was plainly manifest.

The system of zoning or weighting depends upon the relative area in each watershed between fixed elevations. The lower limit of elevation represents the altitude of the stream-gaging station or lake level, and the upper represents that of the crest of the watershed. Three horizontal zones usually suffice.

These zones can readily be laid out on a topographic sheet, available for most watersheds, and their area determined by planimeter.

Representative snow-survey courses are established in each zone, and the seasonal percentage of snow cover for each zone is determined in terms of its own normal. The average of these zonal percentages when weighted for the relative area of its own zone represents the weighted average for the basin.

The drawback to this system is the present lack of snow-survey courses at lower levels, and the difficulty of finding a course at low levels that may not occasionally be bare at the time of surveys; for some index of snow cover must be had, however poor the season. Otherwise all definiteness is gone. Advantage is gained from using the system only when the zonal percentages differ from each other.

Bridging

In cases where funds are insufficient for surveying all the basins in a series, the method of bridging can be used with a fair degree of accuracy. This is merely using the average of the seasonal percentage of flanking basins as representing the seasonal percentage of the basin intersituated. Thus in the Walker Basin, in which crest snow-survey courses are remote from habitations, preliminary estimates of snow cover are made March 1 by the simple expedient of using the average of the percentages at the crest stations in the Mono and Carson Basins, though distant 60 miles apart, and averaging this with the seasonal percentage of the eastern outpost of the Walker Basin, which is readily accessible. Thus the chance of oscillation from any direction is avoided.

Occasionally, a final forecast has been made for the Carson Basin by simply averaging the forecasts for the Walker and Tahoe Basins, which flank it.

DEVELOPING A NORMAL

In the absence of a normal for either snow cover or run-off, a simple process is to obtain data for the current snow cover and stream flow and apply them provisionally as a standard to the data obtained

during the second and immediately succeeding years, until such time as a normal can be computed. Care should be taken to determine whether the run-off of this first or standard year has been abnormally affected by lack of normal precipitation or by other variable factors after melting began, for otherwise the resulting error would be perpetuated.

If rainfall measurements in the basin are not available, use should be made of those nearest or most reliable, for lack of rain sufficient to cause extreme variation in the run-off will be a general rather than a local phenomenon. If a satisfactory normal for stream flow is already at hand, so that the seasonal percentage of the first year is definitely known, this percentage can be considered as that of the snow cover also, provided no abnormal shrinkage has occurred in the former. From this percentage, the normal of the snow cover can be obtained at once.

A capital example of such pioneering is furnished by the experience of 1919–20 in the Humboldt Basin. The courses were 1 year old and some melting had occurred before the original measurements could be made. Furthermore, the succeeding stream flow, measured by the United States Geological Survey, had not been announced. On the assumption that the melting was 3 inches of water (based on observations in the Sierra Nevada), the original measurements were increased by this amount and were then used as a standard of comparison. On this basis, the snow cover of the season of 1919–20 was found to be 76 percent of that of the preceding season. On the other hand, there had been a probable shrinkage of 25 percent in run-off the preceding season due to general lack of precipitation, which might not occur in the present season. Consequently, a forecast of stream flow approximately equal to that of the preceding season was made, but owing to weather conditions this was reduced in the May forecast to 91 percent.

Although no definite statement of the acre-feet available could be made, the comparison with conditions in the previous season was even more comprehensible to the irrigationist, who still had a vivid recollection of its dryness. Later, the stream flow for 1918–19 (April to July) was announced as 115,690 acre-feet, or 49.6 percent of normal. The estimate for 1919–20 was immediately changed to 45.1 percent or 105,278 acre-feet. The actual run-off was 105,950 acre-feet, or 45.4 percent. However, this apparent closeness may be merely deception, for the gaging station is below diversions.

A provisional normal may be based on as few as three seasons' measurements, provided the seasons are complementary. Thus, in the Tahoe Basin the seasons 1909–10 to 1911–12 and 1912–13 to 1914–15 consisted of a heavy, an average, and a light snowfall each, and their normals for crest and eastern outpost stations, measured in inches of water, bear a close resemblance to each other and to the 6-year normal. (The figures, in inches, for the crest were 45.09 and 42.99 for the respective 3-year periods 1909–10 to 1912 and 1912–13 to 1914–15, and 44.04 for the 6-year period 1909–10 to 1914–15; those for the eastern outpost for the same periods were, respectively, 26.14, 27.02, and 26.56.) This rare occurrence has not been repeated and only recently has the average of the snow covers since 1915 approached normal.

Years of very excessive snow cover or run-off should be omitted in forming a normal unless the normal is based upon records for a very large number of years. Otherwise the "reasonable expectation" will be set too high and chronically subnormal years will result. For this reason, in all computations made in the Sierra Nevada surveys, seasons above 200 percent have been omitted temporarily. Such high records include the rise of 225 percent in Lake Tahoe in 1906–07 and the tremendous flows in the Kern River of 345.4, 302.7, and 390.3 percent in 1905–06, 1908–09, and 1915–16, respectively.

Revised Parallel Normals

Where possible, the normal for snow cover and its run-off should be based on the same period of years, and that period should be reasonably long. A normal of 24 years has been computed for the run-off of the Truckee Basin, and the various normals for snow cover there have been expanded to correspond. This normal could have been lengthened still further by including the dry years since 1928, but it was feared that the normal for run-off would thereby be depressed too much. However, comparison with a 41-year record in the Yuba Basin and physical evidence of low lake levels at an earlier period in Eagle Lake not far north indicate that such would probably not be the case.[6]

This 24-year normal of run-off in the Truckee Basin was further used as a standard for expanding the normals for both run-off and snow cover in neighboring basins.

A 24-year normal was likewise computed for run-off in the Humboldt Basin, but owing to the effects of diversion, and also probably to the spotted character of desert precipitation, it did not make a satisfactory standard for expanding the normals in its tributaries.

Spring and Summer Precipitation Stations

In each basin, precipitation gages sheltered from the wind and of sufficient capacity to catch either snow or rain should be centrally located to determine the average precipitation over its area during the period of melting and late summer and autumn run-off. A gage at a central settlement will usually suffice, but occasionally a seasonal gage set farther into the basin will be more satisfactory.

Forecasts

Three forecasts of run-off each season will meet all ordinary needs, except when reservoirs are used for the dual purpose of flood catchment and irrigation storage. Then surveys and forecasts should begin with the first heavy snowfall and continue at intervals throughout the season. The first forecast is made early in April and represents merely the seasonal percentage of the snow cover at its maximum stage before melting has set in. The second is made early in May, when the probable effect of weather on the run-off can be anticipated and the estimate of probable run-off corrected for abnormal shrinkage. The third is made early in June, when the run-off of April and May furnishes a clue to the balance available.

[6] Harding, S. T. Changes in lake levels in the Great Basin area. . . . Civil Eng. 87-90, illus, 1935.

Such forecasts will be requisite to the necessary control of the Truckee River under the new plan of additional storage and careful regulation being formed to serve divergent interests below.

The snow surveys made early in May and in June indicate the relative amount of snow still unmelted, and when a normal for melting has ultimately been obtained these surveys will furnish a check on the forecasts. These later surveys need be made at only a few central stations, but the courses should preferably be on level ground to indicate average conditions of melting at their altitude.

Temperature has such an immediate effect upon the run-off that it is always a disturbing factor in attempts to forecast the rate of run-off for any considerable period. In the case of reservoirs and lakes whose normal decrease from maximum stage due to evaporation is known, forecasts of available water for irrigation and power can be made with fair certainty until autumn, when the new season's storms begin.

ACCURACY OF SNOW SURVEYS AND FORECASTS OF STREAM FLOW

The following summary of the accuracy of 63 snow surveys and forecasts corrected May 15 for probable departure in precipitation during run-off indicates that two-thirds were within 10 percent of accuracy and almost four-fifths within 15 percent. This result was attained with old normals. Of the 6 basins included in the summary, one was a lake basin, another was affected by large diversions above the point of gaging, a third lacked outpost stations. Zoning was employed only in the more recent years of the series. The accuracy of the forecasts—that is, the variation between forecasts and actual run-off in percentage of normal run-off—is shown for various percentage classes in the following tabulation:

Accuracy within following percentage based on normal run-off:	*Number of forecasts*
0 to 5 percent	27
5 to 10 percent	14
10 to 15 percent	7
15 to 20 percent	6
20 to 25 percent	5
25 to 30 percent	3
30 to 35 percent	1
Total	63

ORGANIZED EFFORT ESSENTIAL

Single-basin surveying is sometimes unavoidable, but larger public service with increased accuracy and relatively decreased expense can be rendered by wide-area surveying with a central agency directing the work. In this way overlapping can be avoided. Furthermore, early knowledge of the latent water resources of the range would permit power companies in deficient basins to make adjustments by "tying-in" with their more fortunate associates.

Where watersheds cover two or more States, cooperative snow surveying is essential either by the Federal Government or by the States. Such watersheds are the Sierra Nevada series and the Colorado and Columbia Basins. Water districts, power companies, and municipalities should be included in the cooperation to obtain understanding and cooperation from the public.

COST OF SNOW SURVEYS

The cost of surveying a basin depends upon the number of its course and their accessibility. In the Tahoe Basin, the "control" basin of the central Sierra section, with its seven stations and a circuit from Reno of approximately 320 miles by train, automobile, ski, sledge, and motorboat, the April survey requires the equivalent of 13 days by a party of two persons, or proportionately less by the three parties that usually do the work. In the Yuba and Carson Basins, 4 to 6 days are required. But in the Walker Basin 10 days of strenuous effort and 110 miles of snowshoeing are necessary to cover the two forks and reach the almost inaccessible crest stations between the Walker and Tuolumne Rivers. Surveys on May 1, because of their small number,

FIGURE 8.—Refuge hut on slope of Mount Rose at an altitude of 9,000 feet; headquarters of the snow surveys on Mount Rose.

require far less time, being confined mainly to the crest stations in the Carson, Tahoe, and Yuba Basins.

The present problem is to penetrate the higher basins of the Sierra Nevada far enough to make an accurate determination of their snow cover. To accomplish this chains of refuge huts a day's march apart must be constructed and provisioned. The only requirement is a preliminary winter reconnaissance to find sites where the snow lies sufficiently shallow to permit entering the huts without effort. To make the latter problem simpler, a "Santa Claus chimney" may be constructed as an entrance. The refuge-hut system is now well established (fig. 8).

To the expense of the actual surveys must be added the initial cost of snow samplers and snow traveling equipment, this cost depending on the number of parties in the field. The sum of $15,000 was suggested as the annual expense for conducting the entire system of surveys

throughout the Sierra Nevada. By means of contributions from cooperators, the legislative appropriations are being kept within this limit.

LIMITATIONS

The snow surveys are limited in accuracy corresponding to the increase in the relative precipitation during run-off. Since this relative precipitation is least on the Pacific coast and increases steadily to the Continental Divide, the parallelism of the snow cover and run-off likewise diminishes toward the east. Thus the ratio of precipitation during run-off (April–July) to the snow cover or precipitation during November–March varies from 18.2 percent in the Sierra Nevada to 85.7 percent in the Continental Divide and 238.2 percent in the Great Plains at Denver. This disparity with coast conditions persists in Montana [7] and is even greater in Canada, where the percentage reaches 284.9 percent at Calgary.

However, since the snow cover during melting has the character of continuous precipitation, its effectiveness far exceeds that of a similar quantity of occasional rains, which are partly wasted in repriming the

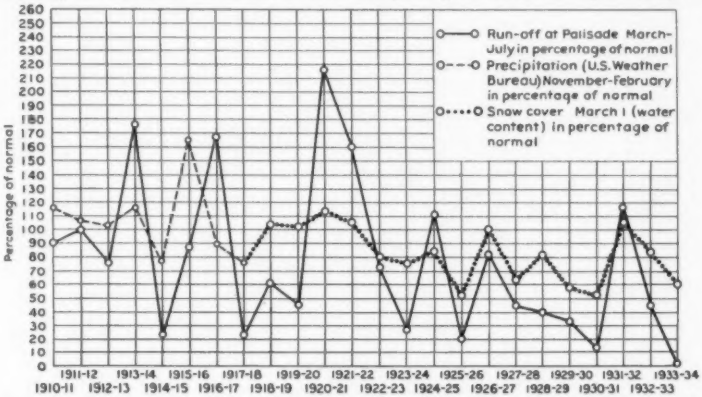

FIGURE 9.—Comparison of snow cover and run-off, Truckee River Basin, exclusive of Lake Tahoe, 1912–13 to 1933–34

soil. Thus the percentage of loss in run-off due to complete lack of normal summer precipitation will probably range from 16 percent in the Sierra Nevada to approximately 30 percent on the Continental Divide. In the Plains region, the loss may vary from 75 to 90 percent.

Figures 9 and 10 show the degree of steadiness between the snow cover and the run-off under ideal conditions of heavy snow cover, shallow stream bed, and relatively light summer precipitation, and the difficult conditions of light snow cover, alluvial stream channel, and relatively heavy summer precipitation. But even in the latter case, the analysis of the affecting factors has brought a fair degree of accuracy in forecasting.

SNOW SURVEYING IN PRACTICE

The simple principles already outlined form only a part of the problem of snow surveying, for the requirements are frequently complex.

[7] The ratio of November through March precipitation to that of April through August is as follows: Billings, 1:2.76; Havre, 1:3; Helena, 1:2; Miles City, 1:2.7.

Therefore, adjustments and experimentation are essential in each phase of the work. A simple enumeration of the problems already encountered [8] opens a wide field, even though uses other than for forecasting stream flow are omitted. Of these problems one was a forecast of how often Lake Tahoe would fall below its outlet during the next 50 years under present regulation. Another was an estimate as to how long it would require Lake Tahoe to regain its normal level if artificially drawn down. A third was an estimate as to the probable normal run-off of the East Walker River, Nev., for which only 2 years of record existed. A fourth was the probable run-off high up on the West Walker based upon the run-off much farther down the stream. A fifth was the relation of run-off to precipitation on the Continental Divide.[9]

Special snow-survey systems have also been worked out for the Klamath and Tule Basins in Oregon and California, for the Coeur d'Alene in Idaho-Washington, and for the Bow in Canada. The first basin was typical of streams flowing from a dry to a wet zone.

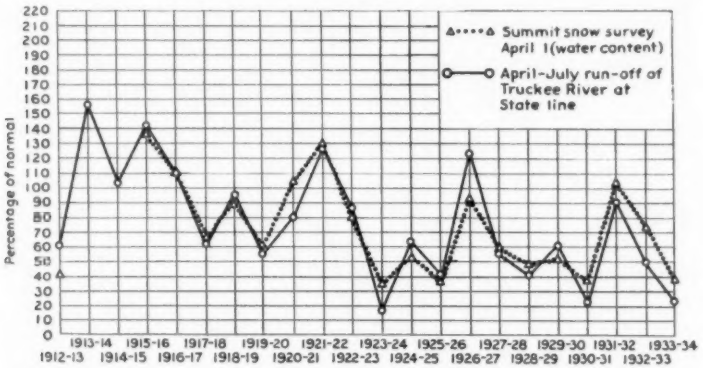

FIGURE 10.—Comparison of snow cover and run-off, upper Humboldt Basin, 1910–11 to 1933–34.

The second represented a dry lake bed that could easily be flooded. The third was a basin whose storage was small as compared with its total discharge, and consequently required careful forecasting to conserve late waters without overflowing the reservoir. The fourth represented run-off from snow and summer rains in about equally effective quantities. Its source was so rugged that parallel and less rugged watersheds had to be sought for the snow surveys.

At the present time, a cooperative effort is being made to improve forecasting in the Humboldt Basin, Nev.,[10] where scant snow cover, relatively heavy precipitation during run-off, numerous diversions above gaging stations, alluvial stream bed, tortuous channel, and tight dams create obstacles for the forecaster. The universality of the problem makes this basin an ideal laboratory for the study of snow surveying.

[8] Unpublished.

[9] CHURCH, J. E., and JONES, E. H. PRECIPITATION AND RUN-OFF AT THE CONTINENTAL DIVIDE. Engin. News-Rec. 94:190-95. (Discussion by H. P. Boardman, p. 195.)

[10] CHURCH, J. E. SNOW SURVEY PROBLEMS IN THE HUMBOLDT BASIN, NEVADA. Reprinted from State Engineer's Report, 1932, Distribution in the Humboldt Basin.

FORECAST SYSTEMS FOR THE COLORADO AND COLUMBIA RIVER BASINS

The following analysis of the Colorado and Columbia River Basins has been made as a basis for the snow-survey systems that have now become essential for their regulation.

COLORADO RIVER BASIN

The Columbia and the Colorado together drain the entire western slope of the Rocky Mountains from New Mexico into Canada (a distance of approximately 1,300 miles) and furnish an annual water flow of approximately 169,000,000 acre-feet at the ratio of 9:1. The Colorado has a run-off of 17,500,000 acre-feet—a large run-off, but relatively small when compared with that of the Columbia.

Of the two projects, the forecasting of the Colorado is more pressing because of the approaching completion of the Boulder Canyon Dam. This project is also far simpler, for unlike the Columbia, the Colorado, with the negligible exception of the Gila, rises entirely in the highlands of the Continental Divide and receives practically no additions toward its mouth. Thus the area of 225,000 square miles above Yuma, Ariz., is reduced for forecast purposes by about one-half, and the crest line of 760 miles is reduced to 550 miles. Furthermore, 3 tributaries—the Green, the Grand, or upper Colorado, and the San Juan—furnish 87.1 percent of the mean annual run-off at Yuma of 17,500,000 acre-feet; that is, about 15,000,000 acre-feet. Of the 15,000,000 acre-feet thus furnished, 2 of these 3 tributaries or feeders, the Green and the Grand, or upper Colorado, furnish 12,500,000 acre-feet, or practically 82 percent. In other words, the Green and the Grand or upper Colorado, furnish 71 percent of the entire flow at Yuma. The mean run-off of these streams as computed in 1921 is as follows:

	Acre-feet
Green River	5, 800, 000
Grand, or upper Colorado	6, 600, 000
San Juan	2, 700, 000

Since the San Juan is highly erratic in its run-off and very important in the early season operations of the Boulder Canyon reservoir, all three tributaries should be included in any detailed plan of snow surveying. There will thus be included the watershed crest from the Colorado-New Mexico line almost to Yellowstone Park and then southwesterly to central Utah. Hence, of the seven States immediately interested in the Colorado River—Wyoming, Colorado, Utah, New Mexico, Arizona, Nevada, and California—only Wyoming, Colorado, and Utah contain the primary and essential snow-survey courses. Simpler still, the joint forecast for these three tributaries will become the forecast for the main Colorado below. Precipitation in the semiarid region below the tributaries can have no more than a minor effect.

Unlike the Columbia, the Colorado has far more irrigable land tributary to it than it can serve. Consequently, close regulation of this stream will be essential in order to guard against floods and yet give maximum service to irrigation and power. To accomplish this, a snow-survey system should be begun immediately and developed to highest efficiency as the maximum use of the stream draws near.

COLUMBIA RIVER BASIN

The mean annual run-off of the Columbia at The Dalles is approximately 151,500,000 acre-feet. This tremendous flow of the Columbia is furnished by three principal tributaries—the upper Columbia with the Kootenay (50,000,000 acre-feet), the Clark Fork-Pend Oreille (19,000,000 acre-feet), and the Snake (45,000,000 acre-feet). The combined system covers with a more or less complete network the entire arid region of Idaho, Oregon, and Washington, and thus guarantees to these States a permanent foundation for agricultural and power development. The chief problem, especially downstream, will be the lifting of water to the highlands, and its solution may be the power ability of the stream itself.

The three tributaries mentioned (the upper Columbia, Kootenay; the Clark Fork-Pend Oreille; and the Snake) supply 77 percent, or about 117,000,000 acre-feet, of the total annual flow of the Columbia at The Dalles, and their individual basins are so large and their flow so abundant that at least two of them have become centers for a series of great reclamation projects. Of the tributaries, the Spokane has long been the source of interstate power.

The problem of forecasting the April to July run-off of the Columbia is virtually the problem of forecasting the run-off of its individual feeders, for the interests served are on the tributaries rather than on the main stream. However, the collective forecast for the feeders would represent the forecast for the main stream. This is shown by the record of 1913 to 1921. During that period the maximum annual variation between the collective run-off of the major feeders and the run-off of the main stream at The Dalles was within 7 percent; and the maximum variation for April to July was within 11 percent, although divergences of 20 to 35 percent frequently occur between the tributaries themselves. On the basis of fragmentary records, a similar closeness of agreement prevailed throughout the preceding decade. However, forecasting for even the individual feeders is far more complex than on the Colorado. Precipitation during April to July grows relatively heavier with increase in distance from the Pacific coast, and the snow cover on the upper Columbia watershed melts slowly during this period, thus catching and ultimately transmitting to the stream the bulk of the precipitation. Therefore, the snow cover on April 1 represents the minimum rather than the probable flow of the stream.

The lower Columbia drains the Cascade and Coast Ranges, which are here of low elevation and transmit the bulk of their snow immediately to the streams. For instance, 57 percent of the run-off of the Willamette occurs in December to March and 27 percent in April to July. Furthermore, the precipitation on the Willamette watershed is relatively light during April to July and adds little to the summer flow in the lower Columbia. On the other hand, the flow of the Columbia above The Dalles is only 17 percent in December to March and 61 percent in April to July. Consequently, the upper and lower Columbia are complementary to each other. Whatever late spring and summer rise occurs in the Columbia will be due to the snow on the Continental Divide. On the other hand, except for the influence of the chinook, the high water in winter should be due to heavy precipitation in the Cascade and Coast Ranges and should occur mainly in the lower Columbia and its immediate tributaries.

SUMMARY

Snow, while falling, is the plaything of wind currents and so resists exact measurement as precipitation. Consequently, it cannot satisfactorily be measured as is rain in a catch gage. On the other hand, after falling, snow is an elastic substance that cannot be measured in terms of depth only as is rain. To meet these two problems a snow sampler was devised that would quickly measure not only the depth of the snow but its water content as well.

However, in the semiarid West streams are fed almost entirely by snow fields, and the water must be carefully apportioned. Even if it were possible to determine the exact quantity of water in the snow field or the net amount that would ultimately reach the stream draining it, it would not be feasible to do so.

Recourse was therefore had to the percentage system of forecasting, for it was found that the relative snow cover throughout a basin was the same wherever measured provided neither drifting nor melting had occurred. To avoid the errors that might arise from drifting, long courses with 25 to 50 samplings were employed, and the average was taken as indicating the snow at that point. Melting was rare and was met by a system of altitude zones. It was now merely necessary to maintain a single fixed course in each zone to determine the relative amount of snow in the basin. Frequently, if melting had not occurred, a single course would serve all zones. This course, if averaged for a fair number of years, would give a "normal" or "mean" water content by which to estimate the percentage relationship of coming seasons. This percentage was obtained by dividing the new snow cover by the mean snow cover; that is, by the average of all the snow covers preceding.

This percentage relationship was found to correspond closely to a similar percentage relationship of run-off in the stream below into which the snow field was discharging. Thus a 75-percent snow cover on April 1 assured an approximately 75-percent run-off during the months of April through July, after which the streams rapidly run dry. The only divergence found was caused by lack of the precipitation that normally falls during the run-off season. This, however, can be fairly well estimated after the first 6 weeks, and corresponding corrections made in the estimate.

So uniform is the snow cover for great distances along the axis of the Sierra Nevada, that usually variations of less than 20 percent occur over distances of 100 miles. Thus the run-off forecast for one stream can be applied also to its neighbor and even to its neighbor's neighbor, and likewise to streams on opposite sides of the crest.

Accuracy within 10 percent in the forecast is usually possible. Even in the case of a single group of snow courses at Summit Station at the crest of the Truckee Basin in the Sierra Nevada, the divergence between snow cover and run-off in 12 years out of 17 was less than 10 percent.

A larger comparison under difficult conditions indicates similar accuracy. In 63 forecasts for the Truckee, Tahoe, Carson, West Walker, south Yuba, and Mokelumne Basins, covering 19 years, 41, or practically two-thirds, were within 10 percent of accuracy, and all were within 31 percent. Twenty-seven, or nearly one-half, were within 5 percent. This system is known as the percentage, or Nevada, system.

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Snow surveys are limited in accuracy in proportion to the increase in the relative precipitation during run-off. Since this relative precipitation is smallest on the Pacific coast and increases steadily to the Continental Divide, the parallelism of the snow cover and run-off likewise diminishes toward the east. Thus the ratio of precipitation during run-off (April through July) to the snow cover or precipitation during November through March varies from 18.2 percent in the Sierra Nevada to 85.7 percent in the Continental Divide and 238.2 percent in the Great Plains at Denver. This disparity with coast conditions persists in Montana and is even greater in Canada, where the percentage reaches 284.9 percent at Calgary.

However, since the snow cover during melting has the character of continuous precipitation, its effectiveness far exceeds that of a similar quantity of occasional rains, which are partially wasted in repriming the soil. Thus the loss in run-off due to complete lack of normal summer precipitation will probably range from 16 percent of normal run-off in the Sierra Nevada to approximately 30 percent on the Continental Divide. In the Plains region, the loss may vary from 75 to 90 percent.

Notwithstanding its limitations, snow surveying is valuable in forecasting the minimum run-off from a watershed. Such is its purpose where the snow cover is regarded merely as a supplement to ground-water storage and summer rains.

NEMIC PARASITES AND ASSOCIATES OF THE MOUNTAIN PINE BEETLE (DENDROCTONUS MONTICOLAE) IN UTAH[1]

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INTRODUCTION

The mountain pine beetle (*Dendroctonus monticolae* Hopk.) has been known for many years in the lodgepole pine belts of Utah. In 1929 outbreaks of this pest, affecting many thousands of trees, began in widely separated localities.

The most serious outbreaks were on Blacks Fork, Horse Creek, and Smiths Fork, near the Utah-Wyoming line in Summit County, Utah, and Uinta County, Wyo. Another severe infestation developed in the upper Provo River Basin east of Kamas, Utah, between Shingle Creek and Broadhead Meadows. These outbreaks spread rapidly from the original centers of infestation during the years 1930 to 1932. At the end of this time they were checked by a control program inaugurated by the Forest Service, United States Department of Agriculture, which consisted of surveying the areas and burning the infested trees. In the course of this work the nemas described in this paper were collected.

HISTORICAL REVIEW

A small outbreak of the mountain pine beetle on lodgepole pine (*Pinus contorta* Loudon) occurred on Henrys Fork, Summit County, Utah, in 1924–25. This outbreak apparently was diminishing when control measures were applied and the beetles were practically eradicated. A similar outbreak on Rock Creek, Duchesne County, Utah, about 1915 to 1917 was reduced by unknown natural agencies.

Evidences of previous outbreaks are present in certain localities. "Cat-faced" (scarred) trees with pitch-preserved beetle borings are numerous in the Henrys Fork territory, and the annual rings show that the outbreak occurred between 1870 and 1880. In the Horse Creek territory there is similar evidence of an outbreak about 150 years ago.[3] The rarity of such outbreaks in this locality indicates that climatic conditions, diseases, or parasites have generally effected sufficient control to hold the beetles in an endemic stage and that, unlike conditions which exist in lodgepole pine forests in Idaho and Montana, only occasionally are conditions favorable for serious outbreaks. The studies herein presented show that nemic parasitism was negligible during the outbreak under discussion.

Published information on the nemic parasites and associates of the mountain pine beetle is limited to a recent paper by Steiner[4] in

[1] Received for publication Mar. 30, 1935; issued September 1935.

[2] The writer is indebted to A. G. Nord, supervisor, and Blaine Betenson, assistant supervisor, of the Wasatch National Forest, Utah, who suggested this problem and secured much of the material through the forest rangers under their direction.

[3] NORD, A. G. Oral communication.

[4] STEINER, G. SOME NEMIC PARASITES AND ASSOCIATES OF THE MOUNTAIN PINE BEETLE (DENDROCTONUS MONTICOLAE). Jour. Agr. Research 45: 437–444, illus. 1932.

which three associate species, *Diplogaster occidentalis* Steiner, *Aphelenchoides conurus* Steiner, and *A. acroposthion* Steiner were described from Idaho.

NEMAS COLLECTED

Collections of larvae and adult beetles, together with bark from infested trees, were secured from four localities in Utah, namely, Blacks Fork, Horse Creek, Smiths Fork, and the upper Provo River Basin. Ten species of nemas, 9 of them new to science, were secured from this material. The distribution of these species is given in table 1.

TABLE 1.—*Distribution of 10 species of nemas, including 9 new species, found in 4 localities in Utah*

Species of nema	Distribution [1] of species in locality indicated			
	Blacks Fork	Horse Creek	Smiths Fork	Upper Provo River Basin
Aphelenchulus reversus, n. sp.	+	+	+	+
Anguillulina pinophila, n. sp.	+	+	+	+
Anguillulina magnicauda, n. sp.	−	+	−	−
Aphelenchoides brachycephalus, n. sp.	+	+	−	+
Aphelenchoides talonus, n. sp.	+	+	+	+
Aphelenchoides tenuidens, n. sp.	+	+	+	+
Aphelenchoides latus, n. sp.	+	+	−	+
Panagrodontus dentatus, n. g., n. sp.	+	+	+	+
Diplogaster pinicola, n. sp.	+	+	−	+
Rhabditis obtusa Fuchs, 1915	−	−	−	+

[1] Plus (+) sign indicates presence; minus (−) sign, absence.

Samples of bark from 20 uninfested trees adjacent to those infested with beetles were also examined. The fact that not one species of the nemas associated with the beetles was found in these samples indicated that the nemas might be dependent upon the beetles for transportation from tree to tree and for providing suitable living quarters.

NEMIC ENDOPARASITE OF THE MOUNTAIN PINE BEETLE

A single endoparasitic species belonging to the genus *Aphelenchulus* was found in every locality investigated. About 2 percent of both adults and grubs of the beetle were each infested with 1 to 11 female nemas and, in some instances, scores of eggs, larvae, and immature females. This genus previously has been represented by a single species, *A. mollis* Cobb, 1920,[5] a parasite of the wood-boring beetle, *Cyllene picta* Drury.

APHELENCHULUS REVERSUS, N. SP.

Eggs.—Deposited before segmentation. Size variable, 30μ by 60μ to 42μ by 90μ. Several hundred deposited by each female in the body cavity of the grub or adult beetle. Segmentation and hatching occur immediately after deposition.

Newly hatched larvae.—Length 0.22 to 0.30 mm; width 12μ to 16μ. Cuticle finely striated. Lip region rounded and expanded (fig. 1, *A*). Tail conoid to the small blunt terminus (fig. 1, *B*). Spear exceedingly slender, without basal knobs.

[5] COBB, N. A. ONE HUNDRED NEW NEMAS. Contributions to a Science of Nematology, IX, pp. 301-302, illus. Baltimore. 1920.

Esophagus a slender tube, narrowing as it passes through the nerve ring, then gradually expanding and merging with intestine. Excretory pore a little posterior to nerve ring.

Second-stage larvae.—Measurements of recently molted specimens:

1.5	16.	20.	Juv.	95.	— 0.35–0.42 mm
1.2	3.4	3.7	5.	3.	

Similar in appearance to the young larvae except for the uniformly tapering anterior end (fig. 1, *C*) and the developing gonads. Genital primordium visible at beginning of first molt (fig. 1, *B*). From it the single ovary develops forward until it is about half as long as body, its terminus reflexed a distance equal to 3 to 5 body widths. A prominent gland usually is visible just back of the nerve ring. During this stage little or no increase in body length but marked development in width.

Intermediate forms between this stage and the adults were not found. Apparently it is during this portion of the life cycle that the nemas leave their

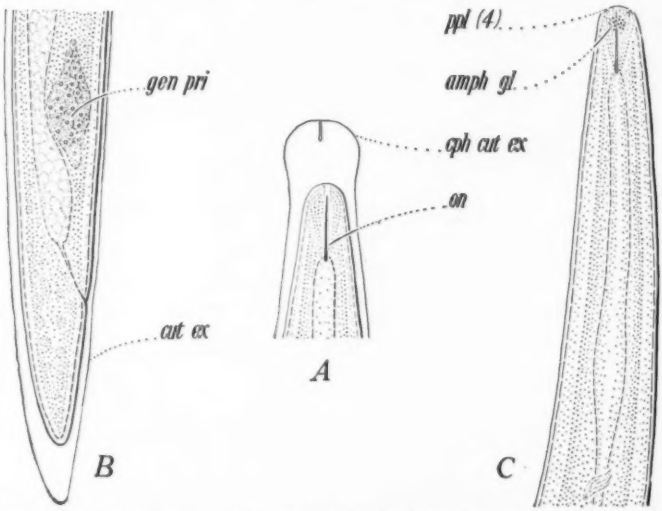

FIGURE 1.—*Aphelenchulus reversus*. *A*, Anterior end of molting first-stage larva: *cph cut ex*, Larval cephalic cuticle; *on*, spear. × 1,000. *B*, Posterior end of molting first-stage larva: *gen pri*, Genital primordium; *cut ex*, larval caudal cuticle. × 1,000. *C*, Anterior end of second-stage larva: *ppl (4)*, Labial papillae; *amph gl*, amphidial glands. × 1,000.

hosts and transfer to other beetles or grubs. However, none was found outside the bodies of the hosts and the method of transfer remains unknown.

Females from grubs and adult beetles.—Length 1.0 to 1.8 mm; width 50μ to 180μ. Vulva 94 to 96 percent. Body bent dorsally, more or less cylindrical throughout greater part of its length but tapering conspicuously at the very narrow lip region, which is not set off in any manner. Cuticle annulated near the head and at the terminus; on some specimens annules conspicuous, on others almost invisible. Body constricted at vulva, especially ventrally. Tail broad, bearing dorsal, hornlike, annulated terminal projection which actually is the upturned original tail of the immature nema. This "horn" apparently becomes upturned as body distends with growth of the internal organs, and pressure is relieved on the ventral side when the broad vulvar opening is formed at the last molt. The four labial papillae almost invisible even from a face view. The amphids lie close to oral opening. Four large glands are prominent feature of head region. Spear 12μ to 14μ long, slender, with short ventrally located aperture. Knobs of the spear vary from obscure to distinct. Lumen of esophagus can be traced only a short distance from the spear. A series of 15 to 18 pairs of conspicuous lateral structures distributed throughout the body. Vulva a broad transverse slit.

Three glands lie opposite vulva, causing constriction of the organs. Anus and rectum absent. Ovary extending forward about three-fourths the length of body, then reflexed a distance equal to 1 to 2 body widths. Oviparous. Females generally burst when removed from the host (fig. 2).

Diagnosis.—Oviparous *Aphelenchulus* with dorsally bent body bearing a prominent, upright terminal "horn." A series of 15 to 18 pairs of conspicuous lateral structures distributed throughout the body. Parasitic in the body of *Dendroctonus monticolae.*

NEMIC ECTOPARASITES AND ASSOCIATES OF THE MOUNTAIN PINE BEETLE

Three nemic species, *Aphelenchoides latus*, *A. tenuidens*, and *Panagrodontus dentatus*, were found living under the elytra of the beetles. In all instances only the larvae were found in this position, the adults

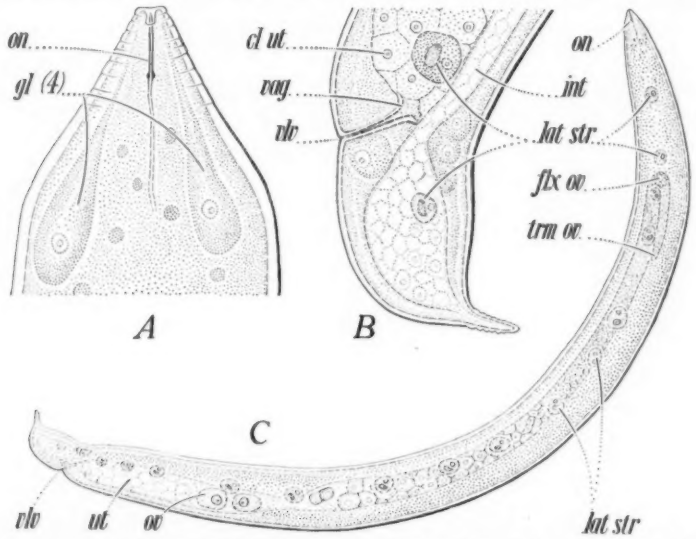

FIGURE 2.—*Aphelenchulus reversus* (female). *A*, Anterior end: *on*, Spear; *gl* (*4*), 2 of 4 glands near head. × 800. *B*, Posterior end: *cl ut*, Cell of uterus; *vag*, vagina; *lat str*, lateral structure; *int*, intestine; *vlv*, vulva. × 400. *C*, Female: *on*, Spear; *lat str*, lateral structure; *flx ov*, flexure of ovary; *trm ov*, terminus of ovary; *ov*, egg; *ut*, uterus; *vlv*, vulva. × 100.

living in the frass. It would seem that such ectoparasitism could cause but little injury or inconvenience to the host and that the principal purpose is to assure transportation to new locations when the beetles abandon dying trees.

Recent borings contained fewer nemic species than did the older ones, a fact which indicates that some species may be carried by secondary insects (Staphylinidae, Tenebrionidae, Ipidae, Histeridae, etc.) which invade the bark soon after the trees are attacked by the mountain pine beetle.

ANGUILLULINA PINOPHILA, N. SP.

Anguillulina pinophila (fig. 3) appeared in every collection made, usually in large numbers. It was the only species found in many trees, especially those in which the beetles had recently become established.

Typically plant parasitic in appearance, it apparently lives only in the tunnels, the lining cells of which are the most probable source of food. Because of the instability of the frass, a spear-bearing nema would experience difficulty in feeding upon it. None of these nemas was found in the bark or in soil about the bases of trees adjacent to those infested with beetles, indicating that the nemas are entirely dependent upon the beetles for transportation.

Anguillulina pinophila is closely related to *A. major* (Fuchs, 1915) new comb. (synonym, *Tylenchus major* Fuchs, 1915),[6] from which it differs because of its narrower, more definitely set-off lip region and coarser striae. In some respects it resembles *A. dipsaci* (Kühn, 1858) Gerv. and V. Ben., 1859; *A. dendrophila* (Marcinowski, 1909) Goodey,

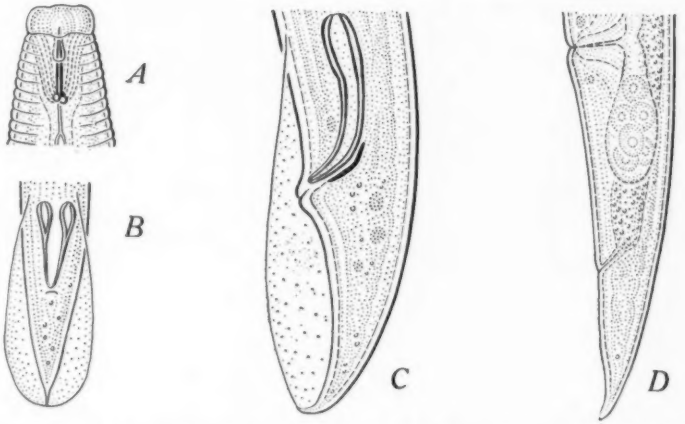

FIGURE 3.—*Anguillulina pinophila: A*, Head. × 1,030. *B*, Male tail, ventral view. × 500. *C*, Male tail, lateral view. × 1,000. *D*, Posterior portion of female. × 500.

1932; and *A. radicicola* (Greeff, 1872) Goodey, 1932. It differs from these species in the form of the lip region and male tail.

Measurements.—

0.5	5.	9.	W	[80] 91.[3]	97.	1.5–2.5 mm [7]
0.4	1.6	2.1	4.	2.6	1.4	
1.	9.	16.	[65] M	97.2		1–1.5 mm
0.8	2.	2.5	3.	1.8		

Size rather variable, females usually considerably larger than males. Cuticle finely striated. Wing area smooth and refractive. Lip region rather flat, almost twice as wide as high, set off by a slight constriction. Spear a little longer than width of lip region, with small, though definite, basal swellings. Esophagus typical, median bulb one-half to two-thirds as wide as neck. Vulva a deep transverse slit. Ovary outstretched, variable in length, sometimes reaching median bulb of esophagus. Posterior uterine branch reaching one-half to three-fourths the distance to anus. Females approaching senility occasionally oviparous. Testis outstretched. Spicula three-fourths as long as tail, most arcuate in distal half. Gubernaculum thin, flat, arcuate, about one-fourth as long as spicula.

[6] FUCHS, G. DIE NATURGESCHICHTE DER NEMATODEN UND EINIGER ANDERER PARASITEN. 1. DES IPS TYPOGRAPHUS L. 2. DES HYLOBIUS ABIETIS L. Zool. Jahrb., Abt. System., Geogr. u. Biol. Tiere 38: [109]–222, illus. 1915.

[7] The letter W, occasionally used in formulas, denotes the widest portion of the body.

Female tail 2 to 3 times as long as anal body diameter, usually rather uniformly conoid to small rounded terminus. Phasmids a little posterior to middle of tail. Distance between vulva and anus variable. Male tail ventrally arcuate, uniformly conoid to pointed terminus. Bursa enveloping tail from terminus to a point opposite proximal ends of spicula.

Diagnosis.—*Anguillulina* of plant parasitic type from tunnels of mountain pine beetle. Lip region truncated, almost twice as wide as high, set off by a slight constriction. Spear slightly longer than width of lip region, with small basal swellings. Spicula three-fourths as long as tail. Bursa completely enveloping tail. Measurements as given above.

ANGUILLULINA MAGNICAUDA, N. SP.

A single female of *Anguillulina magnicauda* was found associated with *A. pinophila* in beetle frass from a tree in the Horse Creek district. The specimen is so outstanding in its characteristics that it appears justifiable to base a new species upon it (fig. 4).

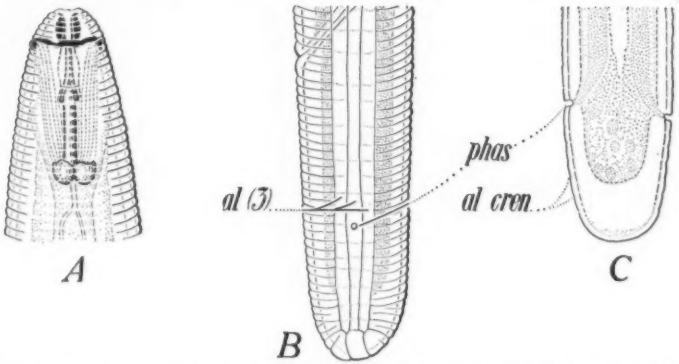

FIGURE 4.—*Anguillulina magnicauda: A*, Head. × 800. *B*, Female tail, lateral view: *al* (3), Wings; *phas*, phasmid. × 800. *C*, Terminus of female tail, ventral view: *phas*, Phasmid; *al cren*, crenation of wings. × 800.

Measurements.—

3. 2	13.	19.	19 60. 17	94. 4	1 mm
1. 4	2. 8	3. 1	3.	2. 4	

Body almost cylindrical, attaining greatest width at base of esophagus. Anteriorly it tapers moderately until lip region is one-half width of neck at nerve ring. Terminus about hemispherical. Cuticle marked by coarse striae that may, especially on tail, be traced across the wing area. Three wings slightly crenate; wing area occupying about one-third the body width, marked by four refractive lines. Lip region continuous with neck contour, marked by fine striae. Minute amphids and labial papillae visible even from lateral view. Labial framework yellow, massive. Spear length about twice width of lip region, basal bulbs strongly developed. The two sections of spear unusually well differentiated. Median esophageal bulb ovate, half as wide as the neck. Posterior esophageal bulb very definitely differentiated from intestine. Excretory pore opposite middle of posterior bulb. Intestine with variable-sized granules. Rectum shorter than anal body diameter. Anus distinct. Vulva a deep, transverse slit. Vagina extending half way across the body. Amphidelphic ovaries symmetrical, outstretched. Although specimen was well developed, no sperms visible in uterus. Tail almost cylindrical to hemispherical terminus, 2½ times as long as anal body diameter. Unusually large portion of terminus hyaline, the "core" only partially filling it. Phasmids prominent, in profile appearing as distinct pockets with fibrous inner connections leading to the lateral cords.

Diagnosis.—*Anguillulina* with rather cylindrical body, practically straight when killed by gradual heat. Lip region continuous with body contour, half as wide as neck at the nerve ring. Labial framework yellow, massive. Spear with huge basal knobs, its length twice the width of lip region. Two ovaries outstretched, symmetrical. Tail almost cylindrical, 2½ times as long as anal body diameter.

Relationships.—Most closely related to *Anguillulina macrura* Goodey, from which it differs in its much wider lip region, more massive spear, and longer tail. The spear, yellow labial framework, and coarse striae of the cuticle similar to those of *Hoplolaimus*, but lip region not set off and spear knobs not dentate.

APHELENCHOIDES BRACHYCEPHALUS, N. SP.

Small numbers of *Aphelenchoides brachycephalus* (fig. 5, *A*, *B*, *C*, *D*) were found living in the frass and tunnels of the bark beetle. Among

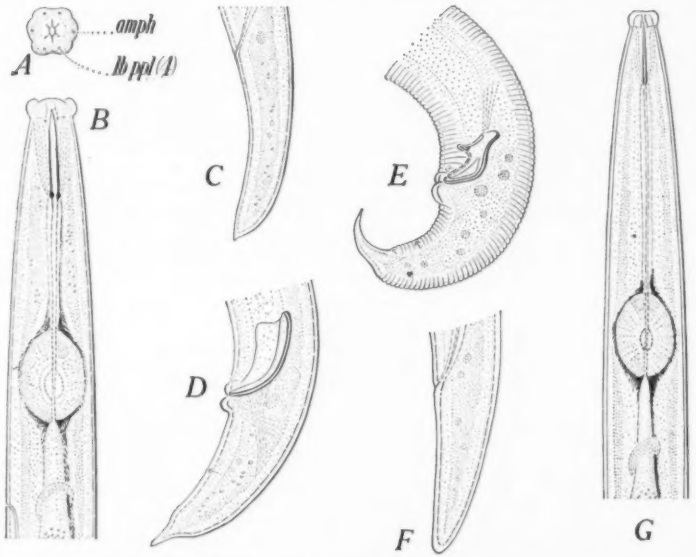

FIGURE 5.—*A–D, Aphelenchoides brachycephalus. A*, Head, face view: *amph*, Amphid; *lb ppl.* (*4*), labial papillae. × 665. *B*, Anterior end. × 665. *C*, Female tail. × 665. *D*, Male tail. × 665. *E–G*, *Aphelenchoides talonus. E*, Male tail. × 665. *F*, Female tail. × 665. *G*, Anterior end. × 665.

the *Aphelenchoides*, *A. brachycephalus* is outstanding because of its broadly expanded, disklike lip region and long, wide spear. The aperture of the spear is easily observed in this species, and it is located ventrally as in other species of *Aphelenchoides* and in *Anguillulina*, *Hoplolaimus*, and related genera. In fact, this feature is a distinctive, previously unrecorded character separating the Anguillulinidae from the Dorylaimidae in which the spear aperture is dorsal.

Measurements.—

2. 5	11.	12.	[57] 76. [12]	94.	0.8–1 mm
1. 3	2. 5	2. 6	3.	1. 7	
2. 5	10.	11.	[25] M	95.	0. 8–1 mm
1. 3	2. 1	2. 2	2. 8	2.	

Cuticle finely annulated, about 17 striae lying between the lips and a point opposite the base of the spear. Anteriorly body tapers much less than in other species to the broadly expanded lip region, which is five-eighths as wide as the neck at the bulb. Body ventrally contracted at vulva. Female tail three times as long as anal body diameter, tapering gradually to the abruptly conoid, mucronate terminus. Male tail somewhat shorter than that of female and more definitely mucronate. Face view reveals lateral lips to be much larger than the submedian. Amphids located slightly ventro-submedially on the lateral lips. The four labial papillae shifted dorsally and ventrally. Spear almost twice as long as width of lip region with distinct joint near middle, the aperture occupying one-half of the anterior portion. Anterior portion of esophagus short, only 1½ times spear length. Bulb slightly ovate, three-fourths as wide as body cavity, its musculature indistinct. Nerve ring located about one bulb width behind bulb. Excretory pore near nerve ring. Granules of intestine beginning just back of nerve ring. Ovary outstretched. Eggs twice as long as body width, and as thick as body cavity. Posterior uterine branch extending one-half to three-fourths the distance to the anus. Testis outstretched. Spicula two-fifths as wide as body, arcurate on dorsal side, ventrally consisting of a slender flexible element. Only two pairs of submedian papillae observed, one pair near middle of tail, other slightly preanal.

Diagnosis.—*Aphelenchoides* with lip region five-eighths as wide as neck at bulb. Spear one-sixth as wide and almost twice as long as width of lip region, the aperture occupying one-half of its anterior portion. Body ventrally contracted at vulva. Spicula arcuate on dorsal side, ventrally a flexible element. Tails of both sexes usually mucronate. Associate of mountain pine beetle.

APHELENCHOIDES TALONUS, N. SP.

Many specimens of *Aphelenchoides talonus* appeared in practically all collections. The female is inconspicuous when compared to the male with his "mitten-shaped" spicula and striking, talonlike terminus (fig. 5, *E*, *F*, *G*).

Measurements.—

1.4	10.	12.	[80] 73. [12]	96.	0.8 mm
0.7	2.	2.1	3.	1.5	
1.4	9.	10.	[75] M	98.	0.8 mm
0.7	1.9	2.	2.1	2.	

Anteriorly body is slightly convex-conoid to the amalgamated, truncate, definitely set-off lip region, which is one-third as wide as the neck at the bulb. Female tail convex-conoid to the blunt, rounded terminus, which bears no mucro. Male tail ventrally arcuate, ending in cuticular, talonlike terminus. Spear slender, without basal knobs, its length equal to twice the width of the lip region. Vulva with slightly elevated labia. Ovary extending forward, then reflexed a short distance. Posterior uterine branch reaching three-fourths the way to the anus. Eggs 2 to 2½ times as long as body width. Testis reflexed a short distance.

Diagnosis.—*Aphelenchoides* with above measurements. Male with "mitten-shaped" spicula and cuticular talonlike terminus. Female tail conoid to the blunt rounded terminus, which bears no mucro. Lip region amalgamated, definitely set off. Spear without basal knobs, its length equal to twice width of lip region. Associate of mountain pine beetle.

APHELENCHOIDES TENUIDENS, N. SP.

Many larvae of *Aphelenchoides tenuidens* (fig. 6) held together in masses of cocoonlike material were found under the elytra of several beetles. Large numbers of the adults were in the bodies of dead beetles and in the frass from the tunnels. In no instance were they found within the bodies of living insects.

Measurements.—

2.1	11.	13.	[55] 75. [15]	95.	0.8 mm
1.	2.1	2.3	2.7	1.7	
2.2	12.	14.	[67] M	94.5	0.75 mm
1.1	2.2	2.3	2.6	2.2	

Body tapering rapidly anteriorly, the width at esophageal bulb being 2½ times that of lip region. Female tail 3 times as long as anal body diameter, slightly convex-conoid to the abruptly conoid terminus, which does not bear a distinct mucro. Male tail slightly bent ventrally, terminus mucronate. Four pairs of submedian papillae present, 2 pairs preanal and 2 caudal (fig. 6, *C*). Spicula about two-fifths as wide as body, arcuate in distal half, proximally almost straight on dorsal side; ventral side flexible when spicula are extruded (fig. 6, *D*).

The distinct striations of the cuticle interrupted laterally by a wing area, which near middle of nema is about one-eighth as wide as body. Lip region amalgamated, caplike, set off by constriction. Vestibule well cuticularized. Spear very slender, its length almost twice the width of lip region, with obscure basal swellings. In living specimens distinct joint observed near middle of spear. Esophageal bulb ovate, with strong musculature, a little more than half as wide as neck: Nerve ring one bulb length behind bulb. Excretory pore slightly back of nerve ring. Intestines densely granular. Ovary outstretched, sometimes almost reaching esophagus. Posterior uterine branch reaching one-half to three-fourths the distance to anus. Eggs half as wide as body; 2½ times as long as wide. Testis usually outstretched, occasionally reflexed a short distance.

Diagnosis.—Aphelenchoides.—Spear twice as long as width of lip region, with obscure basal swellings. Male terminus with mucro, female terminus without mucro. Spicula two-fifths as wide as body, proximally almost straight on dorsal side, ventrally slender, flexible. Male caudal papillae arranged as shown in figure 6, *C*. Associate of mountain pine beetle.

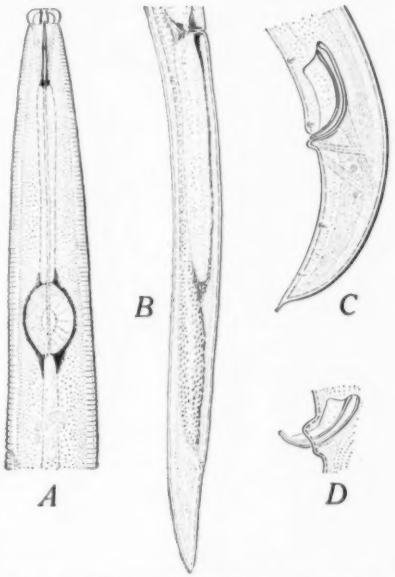

FIGURE 6.—*Aphelenchoides tenuidens: A*, Anterior end. × 665. *B*, Posterior portion of female. × 335. *C*, Male tail. × 665. *D*, Spicula partly extruded. × 665.

APHELENCHOIDES LATUS, N. SP.

Aphelenchoides latus (fig. 7) is very closely related to *Aphelenchoides macrogaster* (Fuchs, 1915) new comb. (synonym, *Tylenchus macrogaster* Fuchs, 1915),[8] from which it differs principally in the narrower lip region and more conoid tails.

Measurements.—

2.5	16.	19.	W	[40] 80.	92.5	0.4 mm
1.5	4.4	4.5	5.5	5.	3.3	
2.7	18.	21.	[44] M		92.3	0.4 mm
1.7	4.4	4.5	5.		3.7	

Body short, unusually broad for an *Aphelenchoides*, tapering anteriorly until lip region is about two-fifths as wide as the neck at the bulb. Wing area marked by four lines. Annulation broad, obscure. Body slightly contracted ventrally at vulva. Female tail slightly arcuate, conoid to pointed terminus. Male tail ventrally arcuate, conoid to pointed terminus. Lip region set off by slight depression, lips obscure. Spear with well-developed basal knobs. Esophageal bulb very large. Hyaline esophagus extends back from bulb unusually long distance before merging with intestine (fig. 7, *A*). Excretory pore located about opposite first granules of intestine. Granules of intestine and body generally large. Vulva a depressed transverse slit, anterior lip overlapping. Vagina at

[8] FUCHS, G. See footnote 6.

first extending in and forward, then bent to nearly right angles with body axis. Ovary outstretched. Posterior uterine branch extending almost to rectum. Female rectum and anus inconspicuous. Two pairs of conspicuous, conical male papillae, one slightly preanal and other at beginning of distal third of tail. Spicula elongate, mitten-shaped, cephalated (fig. 7, *B*). Sex ratio, about eight females to each male.

Diagnosis.—*Aphelenchoides* of small size, and broad body with above measurements. Spear with basal knobs. Esophageal bulb comparatively massive. Intestinal granules beginning almost two body-widths behind bulb. Excretory pore about opposite anterior end of intestine. Body slightly contracted at vulva. Spicula elongate mitten-shaped. Tail of female slightly arcuate, that of male conspicuously arcuate. Terminus acute. Beneath elytra and in tunnels of mountain pine beetle.

DIPLOGASTER PINICOLA, N. SP.

Diplogaster pinicola (fig. 8) was present in limited numbers, which may have been due to the fact that many individuals were suffering

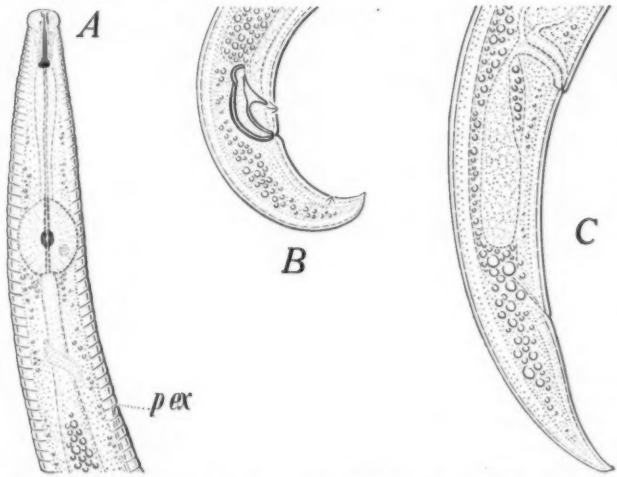

FIGURE 7.—*Aphelenchoides latus*. *A*, Anterior end: *p ex*, Excretory pore. × 800. *B*, Male tail. × 800 *C*, Posterior portion of female. × 800.

from a cutaneous affection, apparently bacterial, causing blisterlike elevations on the head and neck. The dentition indicates that the species may be predaceous, but identifiable food particles were not present in the intestine. The species closely resembles *Diplogaster bütschlii* Fuchs, 1915, from which it differs in possessing longitudinal striations of the cuticle and in the pattern of the cuticular markings.

Measurements.—

0. 6	9.	14.	[20] 51.	[22] 93. 4		1.3 mm
1. 5	2. 4	2. 7	3. 9	1. 9		
0. 8	12.	16.	[52] M	93. 6		1.1 mm
1. 2	2.	2. 4	3. 2	2. 8		

Body moderately slender, tapering anteriorly until width near lip region is about one-half that at base of neck. Female tail convex-conoid to acute terminus, its length about 2½ times anal body diameter. Male tail ventrally arcuate, convex-conoid with spicate terminus. Cuticle marked by fine transverse and longitudinal striae. Longitudinal striae low, obscure (fig. 8, *B*), about 44 at mid body,

decreasing in number toward the extremities. Viewed laterally these longitudinal striae present double rows of refractive, dotlike markings where they cross the transverse striae (fig. 8, *C*). Lip region rounded, with six forward-pointing, conical papillae. Amphids appear as minute oval markings close to the lateral papillae. Pharynx obscurely hexagonal from a face view; viewed laterally it presents two distinct chambers (fig. 8, *D*) bearing a central, massive, arcuate, dorsal tooth. Anterior portion of esophagus four-fifths as long as posterior but broader and more muscular (fig. 8, *A*). Excretory pore a short distance posterior to nerve ring. Intestine densely granular, its lumen sinuous. Ovaries reflexed past vulva. Vulva a transverse slit with protuberant labia. Testis single, reflexed. Spicula yellow, arcuate, slightly cephalated. Gubernaculum thick proximally, with a

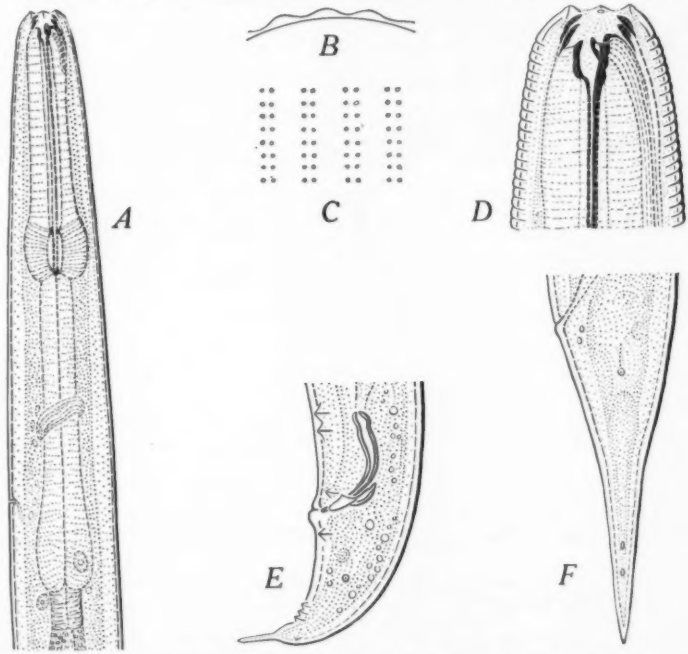

FIGURE 8.—*Diplogaster pinicola: A*, Anterior end. × 500. *B*, Cross section through three longitudinal striae of cuticle. × 2,000. *C*, Pattern formed by dotlike markings of cuticle. × 2,000. *D*, Head. × 1,000. *E*, Male tail. × 500. *F*, Female tail. × 500.

thin troughlike distal extension in which the spicula glide. Eight pairs of male caudal papillae (fig. 8, *E*).

Diagnosis.—Diplogaster with the above measurements. Longitudinal striae 44 at mid body, low, obscure, their presence indicated by double rows of refractive dots. Tails of both sexes less than 7 percent of body length. Six labial papillae, forward-pointing, conical. Pharynx divided into two chambers, armed with single, massive, arcuate dorsal onchium. Female amphidelphic, ovaries reflexed past vulva. Spicula arcuate, cephalated. Gubernaculum thick proximally with thin troughlike distal extension. Eight pairs of male caudal papillae (fig. 8, *E*). From frass and tunnels of mountain pine beetle.

RHABDITIS OBTUSA FUCHS, 1915

Hundreds of the nema *Rhabditis obtusa* (fig. 9) were found in a single tree in which "sour sap" had followed beetle infestation. Fuchs [9] described varieties of *R. obtusa* based principally on the bursal

[9] FUCHS, B. See footnote 6.

formula. This character was variable on the specimens examined and definite varieties could not be determined. In fact, it is doubtful whether the varieties proposed by Fuchs are as definite as he thought them to be.

Measurements.—

2. 3	13.	20.	W [64]	95.	98. 2	0. 8—1. 1 mm
2. 1	3.	3. 6	4.	4.	2. 1	
2. 6	14.	22.	[60] M	95. 6		0. 6—0. 8 mm
2. 2	2. 7	3. 3	3. 4	3. 3		

Bodies of both sexes almost cylindrical between esophagus and genital opening. Neck tapering uniformly to lip region, which is about one-third as wide as base of neck. Female tail short, bluntly conoid. Vulva exceedingly far back (fig. 9, *A*). Striae about 1μ wide at mid body, slightly wider near head. Lip region almost continuous with neck contour. Six conical, forward-pointing, labial papillae were visible but other details of head were always obscured by clinging debris. Amphids minute. Pharynx about three times as deep as wide. Cheilorhabdions and protorhabdions slightly convex. Telostom absent. Esophagus: Corpus

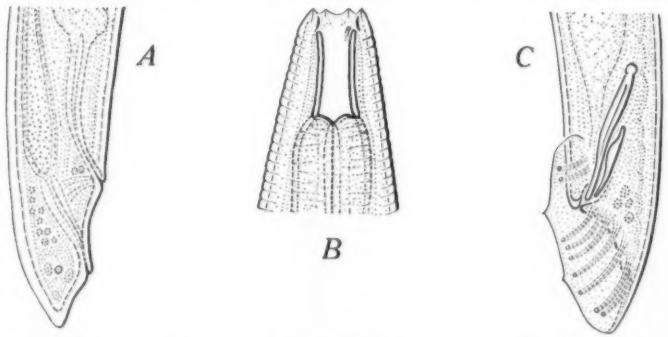

FIGURE 9.—*Rhabditis obtusa* Fuchs: *A*, Posterior portion of female. × 500. *B*, Head. × 1,000. *C*, Male tail. × 500.

cylindrical; medial bulb slightly wider than corpus; isthmus same length as corpus and half as wide; terminal bulb ovate, two-thirds as wide as neck. Nerve ring midway of isthmus. Excretory pore slightly posterior to nerve ring. Female prodelphic. Vulva elevated. Vagina extending almost straight forward. Uterus one-third as long as body. Ovary extending forward from uterus, then reflexed until the blind end reaches one-half to three-fourths the distance back to the vulva. Posterior uterine branch absent. Testis single, extending nearly to esophagus, then reflexed a short distance. Spicula and gubernaculum as shown in figure 9, *C*. Bursa enveloping the tail, with 2 pairs of preanal ribs, then 3 pairs grouped close together just posterior to anus, followed by 4, rarely 3 or 5, pairs; general bursal formula being 2()3, 1, 1, 2.

The species differs from *Rhabditis lambdiensis* Maupas in its slenderer body, continuous lip region, absence of telostom, form of spicula and gubernaculum, bursal formula, and bluntly conoid female tail. It is distinguished from *R. monhystera* Bütschli by the bluntly conoid female tail, by the short male tail enveloped by the bursa, and by the bursal formula.

PANAGRODONTUS, N. G.

Diagnosis.—Cephalobidae. Cephaloboid nemas bearing a flat toothlike projection on the dorsal prorhabdion, which may be opposed by submedian onchia. Lips three, duplex. Amphids minute. Corpus of esophagus broad, cylindrical.

Ovary single, extending forward from the vulva, then reflexed far posterior to it, lacking the double flexure found in *Acrobeles* and *Cephalobus*, the blind end usually reaching the rectum and frequently extending past the anus into the tail. Testis single, terminal portion reflexed. Spicula equal, arcuate, cephalated. Gubernaculum present.

Type species.—*Panagrodontus dentatus*, n. sp.

Panagrodontus differs from other Cephalobidae in possessing a dorsal pharyngeal onchium which sometimes is opposed by submedian onchia.

PANAGRODONTUS DENTATUS, N. G., N. SP.

Measurements.—

1.6	12.	20.	W	30	59.30	90.	0.6 mm
1.9	4.2	4.6	5.6		4.9	3.	
1.3	11.	18.	60 M		90.		0.6 mm
1.6	3.6	4.2	4.2		3.6		

Body tapering both ways from near middle. Tails of both sexes at first dorsally convex-conoid, then convex, ending in a somewhat spicate terminus which occupies one-third to one-half of the total tail length. Transverse striae moder-

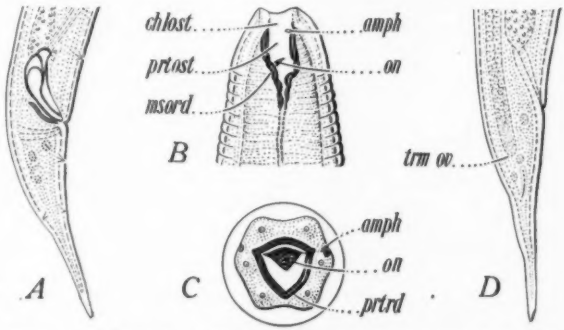

FIGURE 10.—*Panagrodontus dentatus*. *A*, Male tail. × 500. *B*, Head, lateral view: *chlost*, Cheilostom. *prtost*, protostom; *msord*, mesorhabdion; *amph*, amphid; *on*, tooth. × 1,000. *C*, Head, face view: *amph*, Amphid; *on*, tooth; *prtrd*, protorhabdion. × 2,000. *D*, Female tail: *trm ov*, Terminus of ovary. × 500.

ately fine. Wings two, obscure, the area about one-eighth as wide as body near the middle. Lip region rounded, continuous with neck contour. Lips three, duplex, the two subventral being somewhat asymmetrical. Amphids minute. Pharynx:[10] Cheilostom obscure, hexagonal when seen in face view; protostom triquetrous; dorsal mesorhabdion bearing a flat toothlike plate about 2μ long opposed by a niche formed by the submedian mesorhabdions and metarhabdions. Esophagus: Corpus cylindrical, at first almost filling body cavity; isthmus about equal in length to corpus; bulb half as wide as neck with conspicuous valvular apparatus. Intestinal walls at first thin then gradually becoming much thicker with a corresponding narrowing of the lumen. Vulva a transverse slit with elevated labia. Posterior uterine branch rudimentary, its length equal to 1 or 2 body-widths. Ovary extending forward, then reflexed and outstretched, the terminus reaching the rectum or, frequently, extending into the tail. Average size of eggs 20μ × 50μ. Testis single, the terminal portion reflexed. Spicula, gubernaculum, and male caudal papillae as shown in figure 10, *A*.

Diagnosis.—*Panagrodontus* with above measurements. Pharynx armed with a single tooth located on the dorsal mesorhabdion. Tails of sexes similar, at first dorsally convex-conoid, then convex, ending in a somewhat spicate terminus. Spicula, gubernaculum, and male caudal papillae as shown in figure 10, *A*. Associate of mountain pine beetle.

[10] STEINER, G. NOMENCLATURE OF PHARYNGEAL PLATES IN THE NEMATODE CYLINDROGASTER LONGISTOMA (STEFANSKI) GOODEY, AND ITS RELATIONSHIP. Jour. Parasitol. 20: 66. 1933.

SUMMARY

A brief historical discussion of the mountain pine beetle in Utah is given.

A new nemic endoparasite, *Aphelenchulus reversus*, is described and its life history partially outlined.

Eight ectoparasites and associates new to science are described: *Anguillulina pinophila*, *A. magnicauda*, *Aphelenchoides brachycephalus*, *A. talonus*, *A. tenuidens*, *A. latus*, *Panagrodontus dentatus*, and *Diplogaster pinicola*.

New information is given concerning *Rhabditis obtusa* Fuchs, 1915.

Phases of the life histories and habits of these nemas are discussed.

A diagnosis of the new genus *Panagrodontus* is made.

STUDIES ON THE VARIABILITY OF PATHOGENICITY AND CULTURAL CHARACTERS OF GIBBERELLA SAUBINETII[1]

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INTRODUCTION

Variability in pathogenicity and cultural characters in the fungus *Gibberella saubinetii* (Mont.) Sacc. was brought to the attention of the writer during the course of an investigation on the influence of soil temperature upon the development of seedling blight in barley (*Hordeum vulgare* L.) caused by this organism. As a result of these observations the present investigation was directed toward determining the nature, frequency, and magnitude of the apparent variability in *G. saubinetii*, particularly with respect to pathogenicity and cultural characters.

MATERIAL AND METHODS

Perithecia of *Gibberella saubinetii* collected by the writer in the summer of 1933 from barley fields in Illinois, Iowa, and Minnesota furnished the material on which this study was based. All cultures used were grown from ascospores isolated in sets of 8, each set comprising the 8 ascospores from a single ascus. Each subsequent subculture, however, was derived from a single conidium unless otherwise indicated. Ascospores, rather than conidia, were selected as starting points because, theoretically, the ascospores should be homocaryotic, whereas the conidia may or may not be in that condition. Granting the possibility of the existence of nuclei of different genetic constitution, a random assortment of nuclei by virtue of the frequently occurring phenomenon of anastomosis would not preclude the possibility of conidia of different nuclear make-up.

The procedure employed in the isolation of the ascospores was to strip off a bit of the epidermis of a cornstalk bearing the perithecia and wash it in several changes of sterile distilled water. Then it was placed in a sterile Petri dish and the excess water allowed to evaporate. The dish with cover removed was placed under a dissecting microscope and an individual perithecium was picked off with a small flattened needle and placed in a drop of distilled water on a flamed microscope slide. The perithecium was then crushed between the slide and a flamed cover slip. The asci and spores thus removed

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[2] The writer acknowledges his indebtedness to J. G. Dickson, professor of plant pathology, Wisconsin Agricultural Experiment Station, under whose direction this work was undertaken, and to J. C. Walker, professor of plant pathology, Wisconsin Agricultural Experiment Station, and Helen Johann, associate pathologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, for helpful criticism of the manuscript.

from the confines of the fruiting body were observed under the microscope to determine their stage of maturity. Experience has shown that apparently there is a rather definite stage in the development of the asci and ascospores before or after which successful isolation of a set of eight spores from a single ascus is impossible. If the spores are immature, although they may be well defined within the ascus, they are difficult to remove. Furthermore, germination of the spores either does not take place or is at best very weak. If, on the other hand, the contents of the perithecium have advanced beyond the desirable stage of development, the spores are liberated from the ascus while the latter is still within the perithecium, thus making it impossible to isolate the spores with regard to the ascus in which they were borne.

Spores and asci that had attained the proper stage of maturity, as determined by observation, were picked up with a fine wire loop along with the water in which they were suspended, and the suspension was streaked over the surface of hard 4-percent water agar contained in Petri dishes. After about 5 hours' incubation at 24° C., the spores within the asci showed germ tubes, approximately one-half the length of the spore, protruding through the ascus wall. With the aid of the low power of the microscope the locations of asci bearing eight germinating ascospores were marked by scarifying the surface of the agar adjacent to each ascus. When a sufficient number of asci had thus been located, the agar plate was placed under a dissecting microscope, and each ascus was moved across the surface of the agar to an area free from spores and fragments of the perithecial wall. With the asci thus removed from extraneous material and separated at sufficient distances from each other, the spores were "teased" out of each ascus and separated from one another at convenient distances within the field of vision. All manipulations, including the separation of the asci from spores and other material and the removal of spores from the asci, were done by hand with the aid of a sterilized fine glass wire 2μ to 3μ in diameter and bent to form a right angle or semiloop. After the spores were removed from the asci and separated from one another they were examined under the microscope and then allowed to continue germination for a period of about 3 hours. By means of a small loop cutter 0.5 mm in diameter, a cylinder of agar was cut around each spore and the entire piece of agar with the spore on its surface was lifted out and placed in the center of a Petri dish containing hard potato-dextrose agar. Each plate was placed under a miscrosope and again examined to make certain that only a single ascospore had been transferred.

Hyphal-tip cultures were obtained by the same general method as that just described for single ascosporic cultures. After the eight spores from a single ascus had been separated from one another, they were allowed to continue germination until the germ tubes were 5 to 6 times the length of the spore. By means of a fine sterilized glass needle a light scratch was made across the tip of the germ tube, back of a septum, severing it from the spore proper. The free hyphal tip was picked up and placed in the center of a Petri dish containing hard potato-dextrose agar. Two hyphal tips were thus cut off from each spore and grown in separate Petri dishes.

A system of numbering was devised whereby the cultures and culture sets just described could be designated. In this system a number was given to each culture that would indicate the State, the location in the State where the collection was made, the perithecium, the ascus from which the eight spores were isolated, and finally the single ascospores or hyphal tip from which the culture was grown. In table 1 are given the culture sets used, together with the location where the original perithecial material was collected and the date on which the isolation was made.

TABLE 1.—*Cultures used in the investigations reported in this paper, together with the origin of the perithecial material and the date of isolation*

Culture no.	Origin of perithecial material	Date of isolation	Culture no.	Origin of perithecial material	Date of isolation
		1933			*1933*
Ill. 111–1 to 7	Mineral, Ill.	July 14	Minn. 111–1 to 8	Olivia, Minn.	July 17
Ill. 121–H. T.[1]	do	Do.	Minn. 112–H. T.	do	Do.
Ill. 132–H. T.	do	Oct. 15	Minn. 211–1 to 8	Alpha, Minn.	Nov. 2
Iowa 111–1 to 8	Calumet, Iowa	July 14	Minn. 212–1 to 8	do	Do.
Iowa 211–1 to 8	West Liberty, Iowa	July 28			
Iowa 221–1 to 8	do	Oct. 15			

[1] Hyphal tip.

CULTURAL STUDIES

In order to obtain some information as to the range, type, and factors influencing variability in cultural characters, four different experiments were set up. In these experiments potato-dextrose agar and a modification of Brown's agar were used. Each subculture studied was grown from a single conidium unless otherwise indicated. Isolations of single conidia were made by streaking a spore suspension over the surface of hard agar and allowing the spores to germinate. After germination had commenced the spores were picked up singly and placed on the particular agar medium on which they were to be grown. The quantity of agar used in the Petri dishes in which the single-spore colonies were grown was approximately 20 cc. The colonies were allowed to develop in the dark at room temperature, which varied between 21° and 23° C. At the end of 5 days, except in case of first isolation, descriptive notes were taken on each culture with respect to color, type of growth, diameter of colony, type of margin, and the expression of zonation and radiation. Although it is admitted that descriptive notes do not adequately convey a picture of the real differences and changes that occurred in the cultures, nevertheless, such notes, together with photographs, are of value in recording the major variations in cultural behavior.

The following is a brief description of the original colonies grown at room temperature for a period of 4 days:

Color of colony, pomegranate purple[3] concentrated in a central area 2 to 3 cm in diameter and gradually fading to white toward the edge of the colony. Aerial mycelium abundant, extending over the entire colony, and of a cottony texture. Margin of colony, generally regular and entire. No pronounced zonation or radiation detectable. Colony diameter, 8 cm.

[3] RIDGWAY, R. COLOR STANDARDS AND NOMENCLATURE. 43 pp., illus. Washington, D. C. 1912.

The foregoing description applies to all of the original isolates, whether grown from ascospores or hyphal tips (figs. 1 and 2) and regardless of their geographical origin. These isolates constitute a

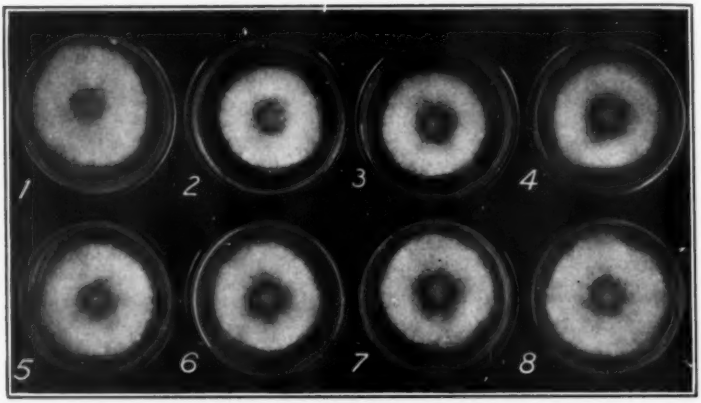

FIGURE 1.—Eight single ascosporic colonies at 4 days of age, grown from the eight ascospores of a single ascus.

type always encountered on first isolation and referred to in this paper as "type A."

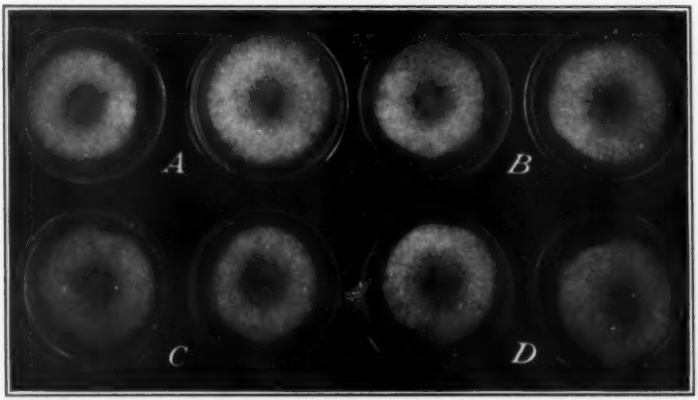

FIGURE 2.—Four pairs (*A*–*D*) of hyphal-tip colonies at 4 days of age. The two members of a pair were grown, respectively, from hyphal tips arising from opposite ends of a germinating ascospore.

EXPERIMENT 1

Experiment 1 was designed to study the effect of the medium and the cultural technic on the changes in cultural characters. Eight single ascosporic cultures from an individual ascus were employed in the experiment. The eight original colonies were strikingly similar in appearance (fig. 1). Duplicate mass transfers were made from each

of the colonies, one transfer to a slant of potato-dextrose agar and the other to a slant of modified Brown's agar. Three days later, spore suspensions were made in these culture tubes and single conidial isolations were made in triplicate from each culture. Part of the spore suspension was used to seed fresh slants of agar from which single conidial isolations were again made 3 days later. This procedure of subculturing from slant cultures that had been transferred every 3 days was repeated 28 times.

During the course of the experiment several of the cultures showed marked changes in cultural behavior from that of the original ascosporic culture. In the cultures propagated on potato-dextrose agar, nos. 1, 2, 4, 6, and 7 were strikingly different by the end of the experiment, while nos. 3, 5, and 8 remained constant (fig. 3). Of the cultures grown on modified Brown's agar, only no. 7 maintained its

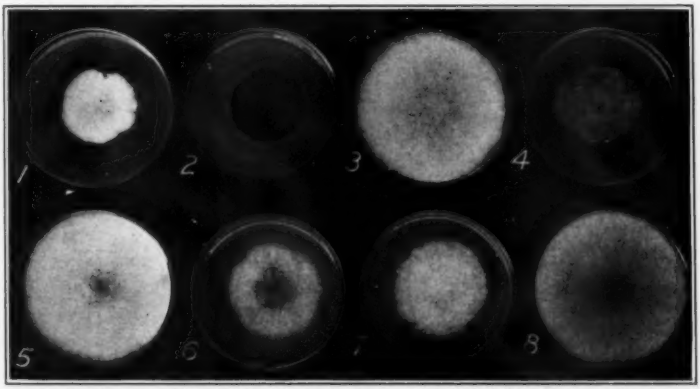

FIGURE 3.—Eight monoconidial colonies after having been subcultured 28 times on potato-dextrose agar. Originally, these cultures were all similar in appearance and were derived from the eight ascospores of a single ascus. Nos. 1, 2, 4, 6, and 7 were strikingly different at end of experiment. Nos. 3, 5, and 8 remained constant.

original appearance, the others having changed decidedly in cultural behavior (fig. 4).

It is apparent that the medium on which the cultures were grown had no influence in determining the extent and magnitude of variation that occurred in cultural characters. Duplicate cultures, each on a separate medium, did not behave in a manner that would indicate their relationship. If the capacity or tendency of a culture to vary in its behavior while growing under artificial conditions is associated with its genetic constitution, then it is not unreasonable to expect cultures arising from the same original ascosporic colony to behave in a similar manner unless irregularities of one sort or another have occurred. Under the conditions of the experiment, in which considerable care was taken to maintain the cultures at a constant environment, there seemed to be no uniformity in the changes that the cultures underwent, regardless of their origin or the media used. The variant cultural types that appeared were generally characterized by a slower radial growth rate and a decrease in abundance of aerial mycelium.

EXPERIMENT 2

The primary object of experiment 2 was to determine what influence the frequency of transfer might have on the cultural behavior of a set of eight single ascosporic isolates from the same ascus.

Duplicate transfers were made from the eight original colonies, which were essentially alike in appearance, to slants on modified Brown's agar. One of these sets of slant cultures was subsequently transferred every 4 days, the other set every 8 days. Each time the cultures were transferred single conidial isolations were made in triplicate from each isolate.

During the course of the experiment the majority of isolates changed in cultural appearance. There was apparently no difference in behavior between the isolates of the group transferred every 4 days and those transferred every 8 days. The time elapsing before the changes became evident and the extent and the magnitude of these

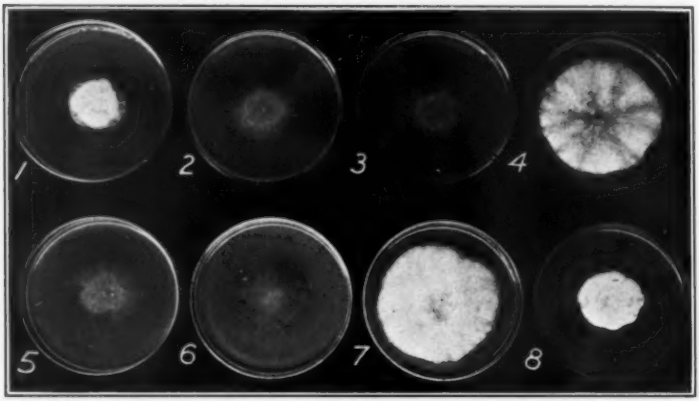

FIGURE 4.—Duplicates of colonies shown in figure 3 and originally derived from the same ascus. They were subcultured 28 times on modified Brown's agar. Nos. 1 to 6 and 8 changed in cultural behavior. No. 7 remained constant.

changes in cultural type were essentially the same in both groups. The results from this experiment, like those from experiment 1, seemed to indicate that changes in cultural characters were not of a systematic, genetic nature.

EXPERIMENT 3

Studies were made to determine the effect of continued subculturing on the stability of a set of eight single ascosporic isolates from an individual ascus. In experiment 3 the isolates were propagated only in Petri dishes instead of in culture tubes, as in experiments 1 and 2. As in the other experiments, the original ascosporic colonies were alike in cultural appearance. When the original ascosporic colonies were 6 days old a spore suspension was made in each dish containing a colony, and from each, single conidial isolations were made in triplicate. Although this procedure was continued for 10 successive conidial generations, no changes in cultural behavior became evident. Each of the 8 cultures was now transferred to a slant of modified Brown's

agar and subsequent transfers were made every 6 days. At each time of transfer single conidial isolations were made in triplicate from each of the cultures. After the second transfer on agar slants, changes in cultural characters began to appear in two of the isolates. The variant cultural types were characterized by a reduced growth rate and a decrease in aerial mycelium.

EXPERIMENT 4

The object of experiment 4 was to determine what effect continued subculturing might have on single cultures. Only 2 cultures were

FIGURE 5.—Diagram of procedure followed in experiment 4 in the use of culture Ill. 132–1A. Each circle represents a colony of monoconidial origin isolated from a colony of the previous conidial generation.

studied in detail, namely, Ill. 132–1A and Ill. 132–1B. These were hyphal-tip cultures from a single ascospore and, on original isolation, were exactly alike in cultural behavior. From each of these 2 original cultures, 10 single conidial isolations were made and plated out on hard potato-dextrose agar. After these 20 cultures were 6 days old, single conidial isolations were again made from some colonies of the previous conidial generation. This procedure was continued for more than 16 conidial generations in the culture Ill. 132–1B and 12 conidial generations in the culture Ill. 132–1A (figs. 5, 6).

In the first conidial generation of culture Ill. 132–1B all of the 10 colonies were alike and similar to the original parent colony, that

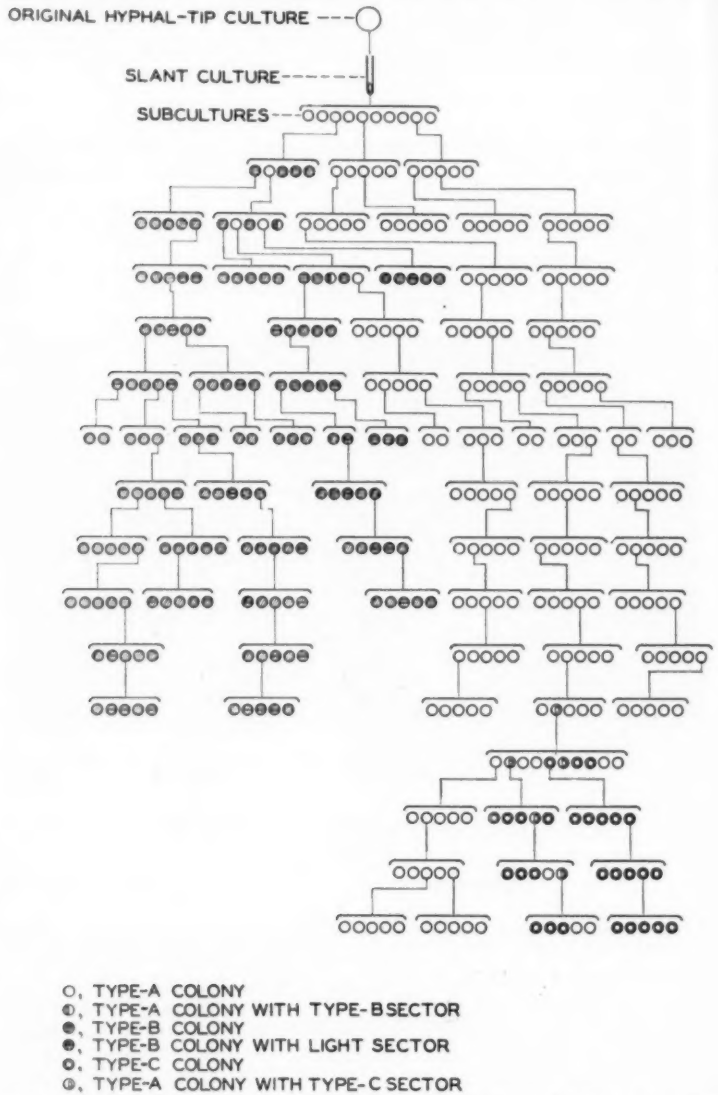

FIGURE 6.—Diagram of procedure used in experiment 4, in which culture Ill. 132–1B was employed. Each circle represents a colony of monoconidial origin isolated from a colony of the previous conidial generation.

is, type A. In the second conidial generation 5 spores selected from one of these colonies produced 5 colonies, 3 of which were alike but

differed distinctly from the parent colony in color, rate of growth, and type of growth. This cultural type will be referred to as type B. The type-B colony, grown at room temperature for a period of 5 days, may be described as follows:

Color of colony, pomegranate purple [4] in central area 0.5 cm in diameter, surrounded by yellow olivaceous zone that fades to pale yellow at edge of colony. Aerial mycelium scant and extending to 1 cm from edge of colony. Margin regular and entire. Color zones as described, radiations in yellow olivaceous zone. Diameter of colony, 5 cm.

The fourth colony was like the parent colony, and the fifth, although resembling the parent colony in the main, had a small sector resembling the type-B colony (fig. 7). Subsequent isolations from type-A colonies of this line produced type A, type B, and type A with type-B sectors. Further isolations from type-B colonies always

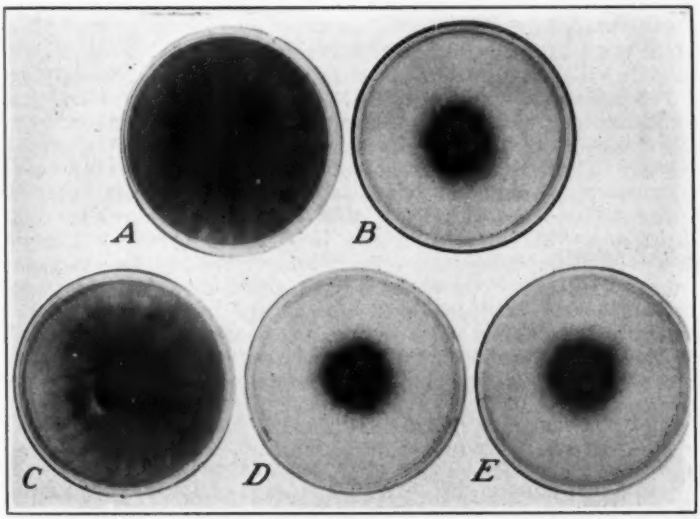

FIGURE 7.—Five single conidial colonies at 5 days of age, all of which were isolated from a type-A colony. *A*, Colony of type A; *B*, *D*, *E*, three colonies of type B; *C*, colony of type A with a type-B sector.

gave rise to colonies resembling the type-B parent, although frequently, after the colonies were 5 days old, light-colored sectors appeared in some of these type-B colonies.

The type-A colonies from the other lines remained constant until the twelfth conidial generation, when one colony produced a type-C sector. Isolations from this colony gave rise to colonies of type C, type A, and type A with type-C sectors. Subsequent type-A colonies remained constant, as did the type-C colonies. The following is a description of the type-C colony:

Color of colony, spinel pink [4] in central area surrounded by narrow zone of pomegranate purple,[4] which, in turn, was surrounded by a zone of spinel pink, which faded gradually to white at edge of colony. Aerial mycelium abundant, extensive, and of a dense cottony texture. Margin regular and entire. Color zonation as indicated. Radiations in spinel-pink zone. Diameter of colony, 6.5 cm.

[4] RIDGWAY, R. See footnote 3.

The culture Ill. 132–1A was studied parallel with Ill. 132–1B. During the course of 12 conidial generations no deviations from the original cultural type were found, that is, all colonies were of type A throughout the experiment.

In this experiment, as well as in the experiments reported earlier in this paper, the results appear to lend themselves to 1 of 2 possible interpretations: (1) Variations in cultural behavior may have been the result of a reassortment and somatic segregation of nuclei of different potentialities that arose through atypical division, or (2) they may have resulted from a fortuitous change in the arrangement and organization of heritable material. The latter interpretation appears to be the more tenable, and until a detailed and comparative cytological study of the variant and normal type cultures is made the possibility of atypical nuclear divisions and subsequent reassortment of these nuclei to account for variation can be advanced only as a hypothesis.

It is not surprising that greater variation in cultural behavior was found in cultures propagated on agar slants than in those carried in Petri dishes. On the limited surface of the agar slant these variations may take place without being observed; in subsequent mass transfers to fresh agar slants a large number of spores and mycelial fragments are carried over, some of which may be of one or more variant cultural types. Continued transferring may well eliminate one or another type until a practically pure culture of a particular and distinct appearance is obtained. Where cultures are carried in Petri dishes and only relatively few spores are isolated from a given colony, the chances of obtaining a variant type culture are considerably reduced even though the variant type may be present but unobservable in the parent colony. If a larger number of conidia had been isolated from colonies carried in Petri dishes, then perhaps greater variation would have been observed.

PATHOGENICITY STUDIES

The pathogenicity studies were undertaken not only with the object of determining the relative virulence of the various cultures, but also with a view to finding a possible correlation between colony type and degree of virulence.

These studies were conducted in benches in the greenhouse where the soil temperature was maintained between 15° and 18° C. The relatively low soil temperature was selected in order to produce a sufficient amount of infection to obtain a differential in virulence between the cultures. Dickson (*9*)[5] has already pointed out that seedling blight of corn, caused by *Gibberella saubinetii*, is favored by soil temperatures ranging from 8° to 20°, whereas at temperatures above 24° no blighting occurs. No attempt was made to control moisture other than to maintain the soil at a moisture content that would permit normal growth and development of the seedlings.

Two lines of corn, obtained through the department of plant pathology of the University of Wisconsin and produced by J. R. Holbert at Bloomington, Ill., were used in the experiments. One line, designated as R4, has proved for a period of years very susceptible to

[5] Reference is made by number (italic) to Literature Cited, p. 161.

seedling blight; while under comparable conditions, the other line, Br10, has been relatively resistant. The line R4 was used in all series of the pathogenicity studies, whereas Br10 was used only in series 6 and 7. In all, 45 single isolates, the cultural behavior of which had not been followed so much in detail as had those isolates used in the section called "Cultural Studies", were employed in the first five series of the experiment. Most of these were single ascosporic cultures from individual asci; a few of the cultures, however, were grown from isolated hyphal tips of germinating ascospores. Originally all of these isolates were alike in their cultural behavior; after being propagated for a comparatively short time on potato-dextrose agar, however, certain variations in their appearance became evident. In order to study these variations in greater detail single conidial isolations were made of each isolate where this was possible. In certain variant types spores were no longer produced and hyphal tips were isolated from the mycelium. Descriptive notes and photographs of these cultures later proved useful in making correlations between colony type and virulence.

Inoculations were made by immersing 50-kernel samples of corn in a suspension of spores and mycelial fragments from an individual culture. Since an extreme variation existed in the sporulation of the cultures, ranging from those in which conidia were very abundant to those in which none were produced, standardization of the inoculum was impossible. Notes on the relative abundance of sporulation of each culture were taken to determine whether a correlation existed between the abundance of conidia and virulence. After the corn kernels had been soaked in a suspension of a single culture for 3 to 5 minutes they were planted in the soil in the bench at a depth of 1 inch. Check plantings were immersed in sterile distilled water for the same period of time and planted in the same bench.

When the control seedlings, grown from the uninoculated seed, had reached the third-leaf stage, which required about 30 days at this soil temperature, both the inoculated and uninoculated lots were removed from the soil and classified according to the severity of infection. The classes in which the seedlings were placed were assigned arbitrary values ranging from 10 for healthy seedlings to 0 for those that failed to emerge because of disease. The number of seedlings in each class was multiplied by the given value of that class and the sum of these values for each class was divided by the number of kernels planted. If the quotient is subtracted from 10, the resulting value represents the disease index. Thus, a disease index of 10 indicates that all seedlings had been killed before emergence, whereas a disease index of 0 indicates that all seedlings emerged and were healthy.

The disease indices of the cultures for each of the five series, together with an average disease index for each culture for all series, are given in table 2. It will be seen at once that there were wide differences in pathogenicity in the cultures. In the set of cultures Iowa 211–1 to 8, originally grown from the eight spores, respectively, of a single ascus, such differences are strikingly evident; the average disease indices range from 3.17 to 9.75, showing an extreme difference of 6.58.

TABLE 2.—*Disease indices of cultures of Gibberella saubinetii used in inoculation studies on an inbred strain of corn, R4*

Culture no.	Disease indices for—						
	Series 1	Series 2	Series 3	Series 4	Series 5	Average for—	
						Individual cultures	Set of cultures
Ill. 111–1	7.76	5.54	4.08	8.20	8.40	6.79	
–2	3.46	2.88	2.68	6.44	5.60	4.21	
–3	8.66	7.92	6.68	9.12	8.52	8.18	
–4	4.00	2.78	1.12	4.92	2.96	3.15	4.66
–5	5.38	4.02	.86	2.58	2.12	2.99	
–6	2.82	1.20	.88	2.44	2.54	1.97	
–7	6.10	4.30	2.84	6.84	6.48	5.31	
Ill. 121–1A	9.60	9.32	8.66	10.00	9.72	9.46	
–1B	6.16	6.50	3.56	7.74	6.40	6.07	
–3A	6.90	7.00	4.44	8.44	7.10	6.77	
–3B	9.62	9.84	8.98	9.96	9.66	9.61	6.55
–5A	5.16	3.48	2.48	6.24	5.68	4.61	
–5B	7.34	6.24	4.18	9.24	8.24	7.05	
–6A	1.40	1.82	.64	1.24	2.96	1.61	
–6B	7.12	5.66	6.58	9.28	7.48	7.22	
Iowa 111–1	.86	1.20	.48	.80	1.24	.91	
–2	6.68	4.98	3.00	6.76	5.36	5.35	
–3	7.40	5.34	3.82	8.88	6.76	6.44	
–4	5.12	3.72	2.72	5.92	5.60	4.61	4.20
–5	2.26	1.40	.72	1.94	1.40	1.54	
–6	.80	.66	.32	1.84	1.00	.92	
–7	8.00	6.34	4.48	8.34	7.72	6.97	
–8	7.10	7.78	3.92	8.64	7.60	7.00	
Iowa 211–1	9.06	9.10	8.60	9.96	8.54	9.05	
–2	6.42	5.06	4.56	7.66	7.08	6.15	
–3	4.88	1.90	2.34	1.86	4.86	3.17	
–4	10.00	9.88	9.24	9.92	9.72	9.75	7.47
–5	5.56	5.22	.66	2.74	2.22	3.30	
–6	9.42	9.62	9.36	9.96	9.74	9.62	
–7	10.00	9.72	9.06	9.90	9.54	9.64	
–8	9.86	8.84	8.30	9.48	8.90	9.07	
Minn. 111–1	4.30	2.36	2.12	5.78	4.52	3.81	
–2	1.00	1.32	.40	1.70	1.12	1.11	
–3	2.64	1.64	.60	2.36	2.60	1.97	
–4	1.04	.88	.32	1.01	1.04	.86	3.55
–5	8.74	8.00	6.48	9.84	9.64	8.54	
–6	1.16	.72	.52	1.40	1.00	.96	
–7	3.76	3.86	1.28	5.82	4.50	3.84	
–8	7.42	6.76	5.94	7.88	8.58	7.31	
Minn. 112–4A	5.86	2.52	.68	3.92	1.52	2.90	
–4B	2.14	.94	.20	2.40	.64	1.26	
–6A	1.78	1.24	.44	1.46	1.00	1.18	1.36
–6B	.86	1.68	.54	1.04	1.06	1.03	
–7A	.80	.68	.92	1.54	1.62	1.11	
–7B	.80	.80	.48	.76	.44	.65	
Average indices for all cultures in each series	5.29	4.50	3.36	5.65	5.12		
Average for control plantings	.79	.65	.62	1.09	1.37		

In every case type-A colonies showing rapid radial growth along with an abundance of aerial mycelium were highly pathogenic. No colonies showing this type of growth were weakly parasitic. A few colonies, however, that did not exhibit such cultural characters were rather virulent. Nevertheless, the indications are that rapid mycelial growth and abundant aerial mycelium are directly correlated with a high degree of pathogenicity in the majority of cases. There may, however, be still other factors responsible for pathogenicity. Similar observations on species of *Fusarium* have been made by other workers. Brown (*3*), working on certain fruit-rotting species of *Fusaria*, has pointed out that the mycelial type of culture is the most pathogenic. He also states that this type of growth is the form found on first isolations from diseased tissue. Harvey (*11*), in a study of the parasitic

abilities of cultures of *F. fructigenum* Fr., found that high virulence was correlated with vigorous mycelial growth.

The data obtained on the relative sporulating ability of the cultures indicate that no positive correlation exists between sporulation and pathogenicity. Some of the most virulent cultures, as well as those that show very weak parasitic tendencies, produce conidia in abundance. Likewise, cultures that produce very few spores may or may not be pathogenic. The sporulating ability of the cultures used in the pathogenicity studies was determined by observing the relative number of spores in a drop of inoculum. No actual counts were made.

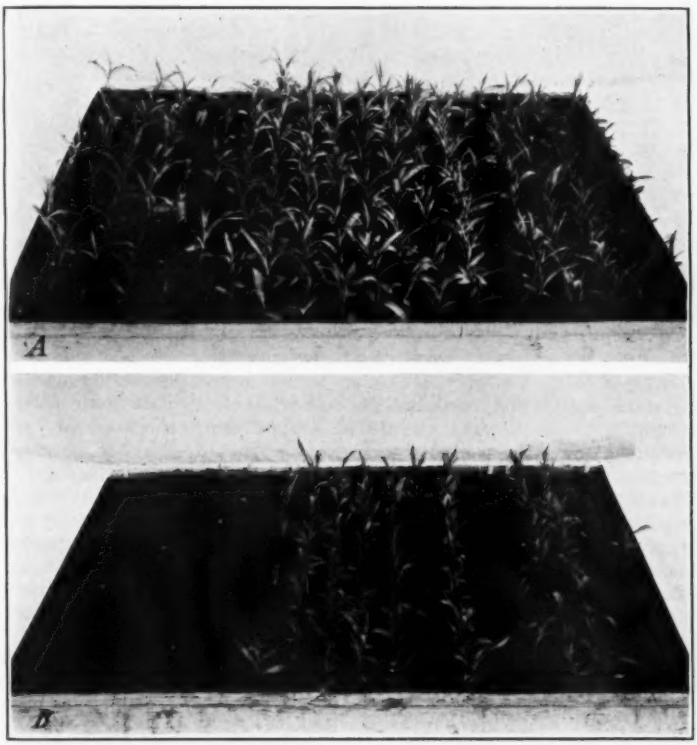

FIGURE 8.—*A*, Corn seedlings of resistant line, Br10, each row inoculated with a single culture. Note the difference in virulence between the cultures used. *B*, Corn seedlings of susceptible line, R4, inoculated with the same cultures as in *A*. Note the relative susceptibility of R4.

In two additional inoculation series (series 6 and 7) both inbred lines of corn, R4 and Br10, were used. In these series an entirely different group of cultures was employed. The same general results were obtained as in the first five series, that is, high virulence was directly correlated with rapid mycelial growth and vigorous aerial mycelium. No indication was found of selective pathogenicity of cultures between two lines of corn, all cultures being more virulent on the susceptible line, R4, than on the resistant line, Br10 (fig. 8 and table 3).

TABLE 3.—*Disease indices of cultures of Gibberella saubinetii used in inoculation studies on 2 inbred lines of corn, Br10 and R4*

Culture no.	Disease indices for indicated culture series on—					
	Inbred Br10			Inbred R4		
	Series 6	Series 7	Average	Series 6	Series 7	Average
Minn. 211–1	8.54	7.62	8.08	9.91	9.72	9.81
–2	8.23	7.80	8.01	9.85	10.00	9.92
–3	8.00	7.58	7.79	9.94	10.00	9.97
–4	7.39	6.58	6.98	9.84	9.68	9.76
–5	8.36	7.94	8.15	9.74	9.86	9.80
–6	8.63	7.66	8.14	9.76	9.20	9.48
–7	7.74	7.90	7.82	9.79	9.84	9.81
–8	4.01	2.94	3.47	8.13	7.80	7.96
Iowa 221–1 (A)	2.09	2.56	2.32	6.57	5.52	6.04
–2	2.53	1.56	2.04	5.57	5.24	5.40
–3	1.95	1.12	1.53	5.40	4.28	4.84
–4	2.19	1.24	1.71	3.99	1.60	2.79
–5	3.73	6.12	4.92	7.35	8.36	7.85
–6	1.18	.64	.91	1.14	.52	.83
–7	8.38	7.12	7.75	9.96	10.00	9.98
–8	5.42	5.28	5.35	9.13	9.32	9.22
Ill. 132–1B–(B)	2.01	1.56	1.78	6.34	5.46	5.90
1B–(B)–8	2.43	1.44	1.93	5.35	3.74	4.54
1B–(A)	8.72	9.20	8.96	9.86	9.76	9.81
1B–(A)–8	4.42	5.46	4.94	8.70	8.88	8.79
Checks (averages)	1.02	.58	.80	1.35	1.19	1.27

EFFECT OF PASSING CULTURES THROUGH THE HOST

Experiments of a preliminary nature were conducted to determine what effect the parasitic habit might have on the cultural behavior of the fungus.

Fifteen lots of corn seedlings, each of which had been inoculated at planting with a different isolate of known cultural behavior, were removed from the greenhouse bench, surface-disinfected, and the diseased tissue plated on hard potato-dextrose agar. After 3 days the fungus had grown out of the diseased portion and could be readily identified as *Gibberella saubinettii*. Mass transfers of apparently pure cultures were made to plates of potato-dextrose agar and 5 days later cultural characters were studied and recorded.

In all cases the reisolated cultures were the same in their cultural behavior as at the time of inoculation, indicating that the sojourn within the host tissue, which was about 1 month, had no perceptible influence on the cultural characters of the fungus. These results are not in accord with the findings of Burkholder (*4*) in a species of *Fusarium*. He reported morphological and physiological changes attending *F. martii phaseoli* Burk. when kept in culture for a long period of time, but after inoculation and reisolation the fungus assumed its original cultural aspects. He also noted that loss of virulence was restored after two inoculations and reisolations. Coons and Larmer (*7*) found that aberrant cultures of *Cercospora beticola* Sacc. have a tendency to revert to the original form after inoculation and reisolation from the host.

DISCUSSION

Throughout the present investigations it has been definitely shown that considerable variation exists among single ascosporic cultures and hyphal-tip cultures of the fungus *Gibberella saubinetii* while growing

under an artificial environment. This variability has been expressed both in cultural behavior and pathogenicity.

An extensive volume of literature has been devoted to the subject of variability of fungi in pure culture. Most of the authors, however, simply report the occurrence of the variations as differences in cultural behavior, morphology, physiology, or pathogenicity, without attempting to analyze their true nature.

Several different views regarding the nature of variations in fungi have been put forward by different groups of workers. Stakman (*18*), Christensen (*6*), and Stevens (*19*) believe that most of the variability in fungi probably is due to true mutation or saltation similar to bud mutation in the higher plants. Brown (*2*) and Mohendra (*17*) also are of the opinion that variants arise as true mutants. La Rue (*14*) suggests that loss of virulence in pathogenic fungi is brought about by the appearance of saprophytic strains, which arise as mutants that are able to thrive better under artificial culture and thus outgrow the parasitic strains.

Caldis and Coons (*5*) have demonstrated that certain variations in the fungi were of a more or less permanent nature and probably induced by nutritional disturbances or a poisoning of the protoplasm. These writers regard such variations as similar to the "Dauermodification" described by Jollos (*13*) for certain Protista.

Holton (*12*), substantiating some of Dickinson's work (*8*), has suggested that in some of the smuts, and in other fungi where true sexuality exists, delayed segregation of certain heritable factors may account for the appearance of variants.

Leonian (*15, 16*) has explained variation in the fungi as a natural phenomenon whereby the culture traces the variability of the species. Attempts by that author to induce mixochimaera in *Fusarium moniliforme* Sheld. were unsuccessful. After two distinct isolates had been grown in combinations for a period, reisolation revealed both parent strains and in addition a new type. The latter was believed to be a dissociant of one of the parent strains and not a heterotype resulting from anastomosis and intimate association of the protoplasm of the two parents.

In opposition to this opinion, Brierley (*1*) holds that the appearance of variants in many instances may be accounted for by a heterocaryotic condition of the original isolate, and that through subsequent culturing a reassortment of nuclei may take place that gives rise to cultures phenotypically divergent from the parent. Brierley further states that true mutation, defined as "a fundamental change in one or more of the hereditary units, and carried from one generation to another", has not been adequately shown in the fungi. He concedes the possibility of aberrant nuclear divisions by virtue of which new forms might arise. Hanson and Smith (*10*) have brought out experimental evidence with *Botrytis* in support of Brierley's contention that a reassortment of the nuclei of a heterocaryotic isolate may give rise to strains differing from the original.

In regard to the pathogenicity of different cultures, Tanja (*20*), working with three isolations of *Gibberella saubinetii* procured in culture from different sources, found that they differed from one another in virulence. Tu (*21*), in an investigation of species of *Fusarium* causing head blight of small grains, has shown that three isolates of *F. graminearum* Schwabe could be separated on the basis of their viru-

lence on several varieties of wheat and on their growth rates. Some information concerning the changes that went on in the cultures employed by these workers before they were tested for pathogenicity would be of interest.

The nature of the variability observed in the investigations reported here does not appear to be directly due to a condition of heterocaryosis in the original isolates. Theoretically, the four nuclei in an ascospore are of the same genetic constitution, and if segregation occurs it takes place in the ascus before the spores are formed. Likewise, all nuclei in the hypha of a germinating ascospore have their origin in the mother nucleus of the cell from which the hypha was produced, and should be genetically alike. Under these assumptions, barring any aberrant nuclear divisions, duplicate ascosporic cultures from a common isolate and hyphal-tip cultures from the same ascospore should behave in the same manner.

Whether aberrant nuclear divisions occur would be difficult to determine cytologically with the material used in these studies. If atypical divisions of the nuclei take place, it is conceivable that only a few of such aberrances could, through the reassortment and segregation of the nuclear complex of a single culture, give rise to forms differing in several respects from the original cultural type. There is also the possibility, and this is perhaps the most tenable explanation, that variations in cultural behavior and pathogenicity in this organism are brought about by gene changes or chromosomal aberrations. That the variant types have appeared rather suddenly and have in some cases passed unaltered through the ascigerous stage strengthens this supposition.

In the experience of the writer, as well as of some other workers, abnormal cultural types were never found under natural conditions. That these abnormal or variant forms are weak pathogenes may preclude their isolation from diseased tissue. In addition, it has been observed that few of these forms pass through the ascigerous stage, which may account for their absence from the isolations made from perithecial material. If these forms do exist in nature they probably do so as saprophytes and are constantly being eliminated through competition and natural selection of the more vigorous forms.

SUMMARY

Single ascosporic and hyphal-tip cultures of *Gibberella saubinetii* (Mont.) Sacc. were studied in relation to cultural behavior and pathogenicity.

The method employed in isolating the eight ascospores from a single ascus is described in detail.

All original ascosporic and hyphal-tip isolates were strikingly similar in cultural behavior regardless of the locality from which the perithecial material was collected. During the course of the studies considerable variability was observed in cultural behavior. The variation was more or less haphazard and did not appear as a result of an orderly segregation within the ascus.

Wide differences were found among the isolates with respect to their ability to cause seedling blight on corn. Some isolates were highly virulent while others were practically nonpathogenic.

A direct correlation was found between colony type and virulence. Those cultures that showed a rapid radial growth and an abundance

of aerial mycelium were always highly pathogenic, whereas those having a relatively slow growth rate and a pionnotes type of growth were generally poor pathogenes. No correlation could be established between abundant conidial production and degree of pathogenicity.

Passage through the host apparently had no influence on the cultural characters of the isolates.

It is suggested that the variability observed in the present investigations may be due to 1 of 2 possible causes: (1) Abnormal nuclear divisions with subsequent reassortment and segregation of a new nuclear complex, or (2) the existence of true mutants.

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RATES OF GROWTH AND NITROGEN ASSIMILATION OF HAVANA SEED TOBACCO [1]

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INTRODUCTION

This investigation was planned to furnish basic information for the intelligent study of fertilizer practices, with particular reference to quantity, source, and time of application of nitrogenous materials. It involved measurements of rates of growth and nitrogen intake of the Havana Seed tobacco crop in the Connecticut Valley during the 5-year period 1929–33. The various plant parts (roots, stalk, crop leaves, sucker leaves, and seed pods) were differentiated in the analyses; hence, a picture of the increase in dry weight and total nitrogen content of this crop is presented by the data.

No effort has been made to interpret these data in relation to the various theories concerning the mathematical laws underlying growth rates, but it is hoped that those interested will avail themselves of this material to test the validity of these theories.

PREVIOUS INVESTIGATIONS

Kosutány [2] presented data on the total dry weight and chemical analysis of tobacco at six dates, from the transplanted seedlings on May 31 to the time of ripening of the seeds on September 17. For comparison with data in the present study, his results, calculated in pounds per acre on the basis of an equal number of plants per acre, are shown in table 1. As to whether the total weight of the plants included roots was not stated.

TABLE 1.—*Total dry weight and nitrogen content of tobacco during its development (after Kosutány)*

Age of plant in field (days)	Total dry weight (pounds per acre)	Total nitrogen (pounds per acre)	Nitrogen	Age of plant in field (days)	Total dry weight (pounds per acre)	Total nitrogen (pounds per acre)	Nitrogen
			Percent				*Percent*
0	10.8	0.20	1.85	55	1,230.0	36.60	2.98
21	81.0	2.20	2.72	77	4,708.0	110.60	2.35
43	643.6	22.60	3.51	99	4,100.0	94.20	2.30

Davidson [3] in data based on the average of three tobacco varieties at three stages of growth (plant bed, topping, and cutting) shows average nitrogen contents of 2.88, 2.97, and 2.73 percent, respectively, at the successive stages, for the whole plant. The leaf at the topping stage contained 4.40 percent of nitrogen, as compared with 3.66 percent at cutting time.

[1] Received for publication Mar. 16, 1935; issued September, 1935.

[2] KOSUTÁNY, T. CHEMISCH-PHYSIOLOGISCHE UNTERSUCHUNG CHARACTERISTISCHEREN TOBAKSORTEN UNGARNS. p. 41. Budapest. 1882.

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Garner and his coworkers [4] measured the growth of tobacco at successive stages on the basis of height of plant to lowermost leafless branch when different forms and amounts of nitrogen were applied in the fertilizer. Sigmoid growth curves, with maximum rate of growth between August 11 and August 26, were obtained with application of no nitrogen and with 40 pounds of nitrogen applied as nitrate of soda. With 20 and 80 pounds of nitrogen applied as nitrate of soda, and 40 pounds as ammonium nitrate, all plants showed no significant reduction in rate of height growth during the final period (Aug. 26 to Sept. 4). The plants were not topped in this experiment.

Vickery, Pucher, Wakeman, and Leavenworth [5] have made studies of rate of growth and nitrogen assimilation of shade-grown tobacco in Connecticut based on results during one season. Their results include measurements of various forms of nitrogen in the plant. Roots were not included. Rates of dry-matter production and nitrogen intake follow trends in close agreement with the data here presented.

Miller [6] gives a comprehensive review of the literature dealing with theories in regard to rates of plant growth.

PROCEDURE

The plants measured in this experiment were selected from a plot of tobacco located on typical Connecticut Valley tobacco soil (Merrimac sandy loam.) Previous to setting, heavy applications of fertilizer, containing 200 pounds of nitrogen (four-fifths as organic nitrogen, chiefly cottonseed meal; one-fifth as nitrate of soda), 100 pounds of phosphoric acid, and 200 pounds of potash, were made. Plants were collected at approximately 10-day intervals. Plants of the same apparent size as those withdrawn were tagged for identification to be measured at the subsequent period. In all cases the plants measured were chosen as a fair average of the plot.

The entire plant was removed, including all obtainable roots. The parts were separated and dried immediately in an oven. The number used for measurement ranged from 20 or more at time of setting to 1 after mid-season, in order to furnish a sufficient amount of material for analysis.

After oven-drying, the various portions of the plant were weighed, ground, and analyzed for total nitrogen by the Kjeldahl method.

At the time of topping for the tobacco on the plot, a sufficient number of plants were left untopped to provide samples of untopped plants up to the time of maturity of the seed pods, in comparison with those normally topped.

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DATA AND DISCUSSION OF RESULTS

For the sake of brevity, the data for the individual years of the experiment (1929, 1930, 1931, 1932, 1933) are not presented. In all cases a similar growth curve was obtained. There was a considerable divergence in the time that elapsed before the beginning of the grand period of growth. In 1929 and 1933, maximum growth rate began at the thirty-fifth day; in 1930, at the thirtieth day; in 1931, at the forty-fifth day; and in 1932, at the fiftieth day. The yields in the two latter years were abnormally low, while in 1930 the greatest growth was attained. In 1929 the crop was destroyed by hail at the sixtieth day, having then attained a growth similar to 1933. In order to weight the data properly, the 1929 crop was assumed to have continued to follow the trend of the 1933 crop for the remaining time.

The dry weights of the various plant parts, based on averages for the 5 years, are given in table 2.

These data are shown graphically in figure 1 by means of smoothed curves. A differentiation of crop and sucker leaves on the topped plants was approximated, on the basis of unpublished data by Berthold [7] of studies made at Windsor in 1930.

TABLE 2.—*Dry weight and nitrogen content of, and total quantity of nitrogen in, various portions and the entire plant of topped and untopped Havana Seed tobacco, and also in the entire crop, at different times during the growth period, 1929–33*

[The data are averaged for a 5-year period and the mean age of harvest was 72 days]

DRY WEIGHT

Age of plants in field (days)	Roots	Stalks	Leaves	Pods	Total	Probable error of mean [1]
	Pounds per acre	*Pounds per acre*	*Pounds per acre*	*Pounds per acre*	*Pounds per acre*	
10	0.99	[2] 0.96	10.05	.....	12.00	±0.76
20	2.23	4.38	30.50	.....	37.11	±4.34
30	12.73	31.35	145.92	.....	190.00	±27.50
40	82.71	189.05	572.24	.....	844.00	±143.00
50	218.00	502.00	1,260.00	.....	1,980.00	±219.00
60:						
Topped [3]	460.00	1,059.00	1,766.00	.....	3,285.00	± 83.00
Untopped	475.00	1,375.00	1,820.00	130.0	3,800.00	±172.00
70:						
Topped [3]	850.00	1,592.00	2,100.00	.....	4,542.00	±251.00
Untopped	900.00	2,385.00	2,190.00	400.0	5,875.00	±295.00
80:						
Topped [3]	1,443.00	1,947.00	2,340.00	.....	5,730.00	±196.00
Untopped	1,475.00	3,040.00	2,490.00	775.0	7,780.00	±313.00

TOTAL QUANTITY OF NITROGEN

10	0.03	[2] 0.03	0.37	.....	0.43	0.04
20	.06	.15	1.13	.....	1.34	.37
30	.35	.98	5.61	.....	6.94	1.37
40	2.19	5.37	22.55	.....	30.11	6.48
50	4.86	12.40	49.14	.....	66.40	7.95
60:						
Topped [3]	8.97	22.03	64.99	.....	95.99	4.96
Untopped	9.03	28.46	68.25	6.50	112.24	7.66
70:						
Topped [3]	14.45	28.62	69.30	.....	112.37	7.54
Untopped	14.22	40.55	73.80	16.60	145.17	8.31
80:						
Topped [3]	19.19	31.74	69.03	.....	119.96	6.88
Untopped	17.26	40.43	69.72	27.59	155.00	11.97

[1] From formula P. E. M. $=0.6745\sqrt{\frac{\Sigma d^2}{n(n-1)}}$.

[2] Topped at 54 days (mean date).

[3] Estimated graphically.

[7] BERTHOLD, K. T. NITROGEN ASSIMILATION—TOPPING AND SUCKERING EXPERIMENT. Unpublished manuscript on file at Tobacco Substation, Conn. State Agr. Expt. Sta. 1931.

TABLE 2.—*Dry weight and nitrogen content of, and total quantity of nitrogen in, various portions and the entire plant of topped and untopped Havana seed tobacco, and also in the entire crop, at different times during the growth period, 1929–33.*—Continued

[The data are averaged for a 5-year period and the mean age of harvest was 72 days]

NITROGEN CONTENT, PERCENT

Age of plants in field (days)	Roots	Stalks	Leaves	Pods	Total	Probable error of mean
	Pounds per acre	*Pounds per acre*	*Pounds per acre*	*Pounds peracre*	*Pounds per acre*	
10	2.75	[3]3.52	3.65	.....	3.56	0.31
20	2.78	3.36	3.70	.....	3.61	.36
30	2.77	3.13	3.85	.....	3.65	.24
40	2.65	2.84	3.94	.....	3.57	.32
50	2.23	2.47	3.90	.....	3.37	.20
60:						
Topped [2]	1.95	2.08	3.68	.....	2.92	.18
Untopped	1.90	2.07	3.75	5.00	2.95	.17
70:						
Topped [2]	1.70	1.80	3.30	.....	2.47	.16
Untopped	1.58	1.70	3.37	4.15	2.47	.14
80:						
Topped [2]	1.33	1.63	2.95	.....	2.10	.23
Untopped	1.17	1.33	2.80	3.56	1.99	.21

[2] Topped at 54 days (mean date).

[3] Estimated graphically.

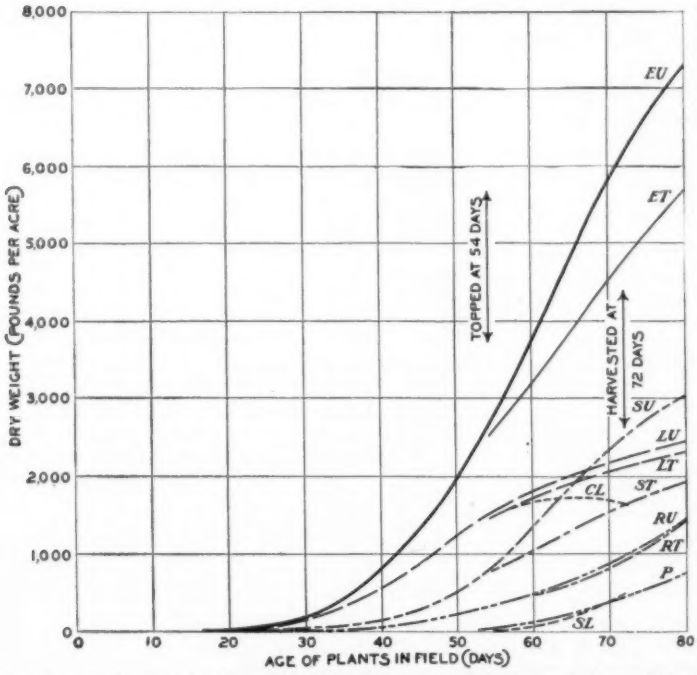

FIGURE 1.—Growth curves of various portions of topped and untopped Havana seed tobacco: *EU*, entire plant, untopped; *ET*, entire plant, topped; *LU*, leaves, untopped plants; *LT*, leaves, topped plants; *CL*, crop leaves, topped plants; *SL*, sucker leaves, topped plants; *SU*, stalks, untopped plants; *ST*, stalks, topped plants; *RU*, roots, untopped plants; *RT*, roots, topped plants; *P*, pods, untopped plants.

GROWTH OF NORMAL UNTOPPED PLANTS

As may be seen from an examination of the charts, the entire plant showed a logarithmic acceleration of growth rate, reaching a maximum between the fortieth and sixtieth days after setting in the field. There was only a slight reduction in total growth with approaching seed-pod maturity. The leaf production was diminished after the fifty-fifth day, at about the time the floral parts emerge. The stalk continued rapid growth up to about the sixty-fifth day, its grand period of growth being about 10 days later than for the leaves. The roots apparently attained their maximum rate of growth about when the measurements were ended, on the average at the eightieth day.

CHANGES IN GROWTH AFTER TOPPING

Removal of the terminal bud and a small section of the end of the stalk along with it had a marked effect on the subsequent course of growth of the various plant parts. The total dry-matter production was markedly diminished, out of all proportion to the amount of dry matter removed in the topping operation (estimated at about 100 pounds per acre). The major difference is due to the decreased stalk growth of the topped plant. There was comparatively little difference in total leaf production, and root growth was nearly identical. No pods were produced on the topped plant, this accounting for some of the difference in total dry matter.

However, it is to be noted that the crop leaves, all being developed at the time of topping, grew very little after topping, and apparently suffered some loss in weight just prior to the harvest date. At the same time the sucker leaves were growing rapidly. Crop and sucker leaves are not differentiated in the final data for the eightieth day, nor for the untopped plant at any time.

NITROGEN CONTENT OF PLANTS

The average nitrogen content, on a percentage basis, for the various parts of the plants at the different dates, is shown in table 2, and graphically in figure 2.

Some interesting relationships are evident. Stalks and leaves, both contained approximately 3.5 percent nitrogen at first sampling and then rapidly diverged. The stalks decreased progressively in nitrogen content to a minimum of about 1.5 percent at the final period, although those of the topped plants apparently showed some decline in rate of decrease, possibly due to restoration of vegetative conditions.

The decreased nitrogen content of the stalk is doubtless associated with the development of woody tissue, so prominent in mature tobacco stalks.

The leaves gradually increased to a maximum of about 3.95 percent nitrogen at about 40 days, or early in the grand period of growth of the entire plant. The percentage content of nitrogen of the combined crop and sucker leaves from the topped plants was at first lower than the untopped. Later this condition was reversed, due to the production of sucker leaves of high nitrogen content. The crop leaves decreased in nitrogen content at a very rapid rate after topping, on the basis of Berthold's data.[8]

[8] Berthold, K. T. See footnote 7.

The roots showed a slight increase in nitrogen content up to the thirtieth day, with subsequent progressive decrease. The topping operation apparently tends to produce a temporary storage of nitrogen in the roots, since the normal rate of nitrogen decrease is slowed down for about 10 days. It is to be noted that the maximum nitrogen content in the roots occurred before that in the leaves.

Pods, when first produced in the bud stage, had a very high nitrogen content of over 5 percent, which decreased rapidly during their

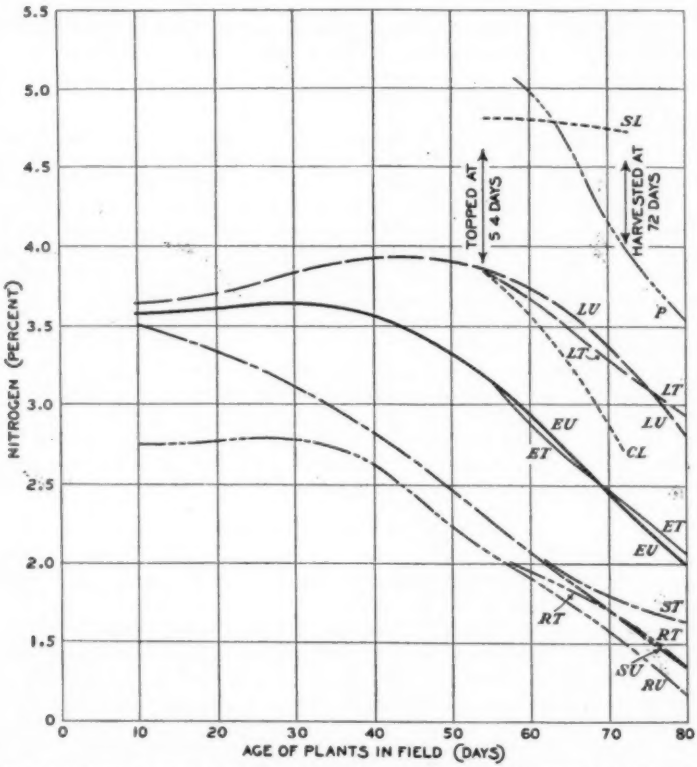

FIGURE 2.—Nitrogen content of various portions of topped and untopped Havana seed tobacco: *EU*, Entire plant, untopped; *ET*, entire plant, topped; *LU*, leaves, untopped plants; *LT*, leaves, topped plants; *CL*, crop leaves, topped plants; *SL*, sucker leaves, topped plants; *SU*, stalks, untopped plants; *ST*, stalks, topped plants; *RU*, roots, untopped plants; *RT*, roots, topped plants; *P*, pods, untopped plants.

development. The measurement was approximately the same as for the seed itself, the latter making up most of the entire weight of the pods.

TOTAL NITROGEN INTAKE OF THE PLANTS

The final objective of this experiment was the measurement of total nitrogen intake by the tobacco plant at various periods of growth. This is the resultant of the two previous sets of measurements and is shown in table 2 and graphically in figure 3.

While on the whole the same general picture is presented as for total dry weight, it is seen that the decline in the rate of nitrogen intake was more rapid during the later stages, due to the previously noted decreases in nitrogen content of the various parts of the plant. Thus a sigmoid curve for total nitrogen in the entire plant is more clearly in evidence, especially for the topped plants.

The translocation of nitrogen from the leaves of the untopped plant and from the crop leaves of the topped plants, is clearly shown. The stalks, despite their continued increase in total weight during the final period, had practically ceased to be a factor in building up the nitrogen in the plant.

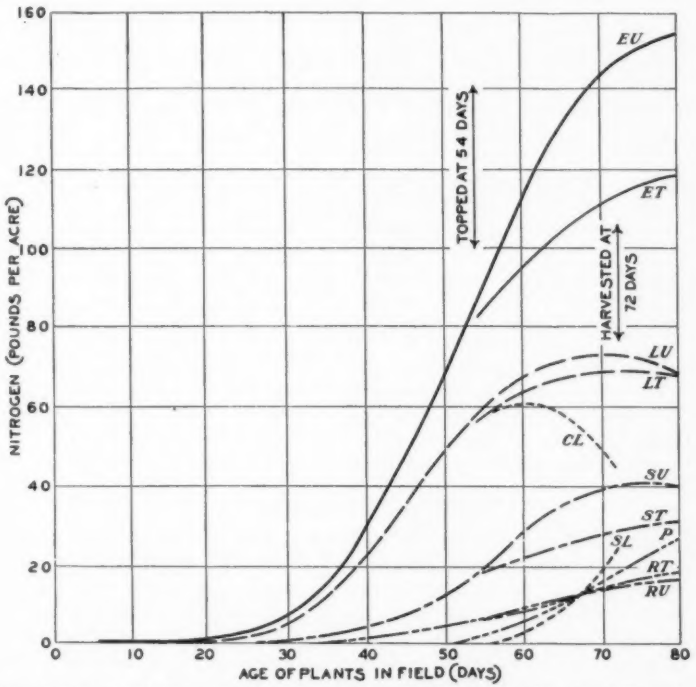

FIGURE 3.—Amounts of nitrogen contained in various portions of topped and untopped Havana seed tobacco in the course of the growth period: *EU*, Entire plant, untopped; *ET*, entire plant, topped; *LU*, leaves, untopped plants; *LT*, leaves, topped plants; *CL*, crop leaves, topped plants; *SL*, sucker leaves, topped plants; *SU*, stalks, untopped plants; *ST*, stalks, topped plants; *RU*, roots, untopped plants; *RT*, roots, topped plants; *P*, pods, untopped plants.

Although growth was still active at the final measurement, nitrogen intake from the soil was rapidly approaching cessation. The building up of nitrogen in the pods of the untopped plant occurred largely at the expense of its leaves.

Under the scheme of fertilization practiced on the field, with 80 percent of the nitrogen applied in the organic form, the amount of nitrate nitrogen in the soil attained a maximum of about 60 pounds per acre in about 3 weeks after setting. Except as interrupted by

leaching from the soil by unusually heavy rains, the nitrate nitrogen liberated by biological activity kept pace with crop removal until about the first of August, normally about 60 days after setting. The nitrates in the soil then decreased rapidly, falling off to less than 10 pounds per acre at the time of final measurement in this experiment. These observations are based on data as to nitrate nitrogen in the soil on the plots from which the growth samples were taken during 1932 and 1933, and in the soils of plots under various nitrogenous fertilizers during 1932, 1933, and 1934.

It is evident that, since the nitrate level of the soil was high until the sixtieth day, there was no limitation in nitrogen intake until this time. It is of interest to note that the untopped plants showed a definite diminution in rate of total nitrogen intake during the time of depletion of nitrates in the soil.

Table 3 gives a picture of the distribution of dry weight and nitrogen in the Havana seed tobacco crop at harvest date. These data were obtained by interpolation from the graphs based on average results over the 5-year period.

TABLE 3.—*Dry weight and nitrogen content of various parts of the Havana seed tobacco crop at harvest date, 72 days after setting*

[Average data, 1929–33]

Plant part	Dry weight	Nitrogen		Nitrogen contained in entire plant
	Pounds	*Percent*	*Pounds*	*Percent*
Roots	950	1.58	15.0	13.2
Stalks	1,675	1.77	29.6	26.0
Suckers	507	4.85	24.6	21.5
Crop leaves	1,643	2.73	44.9	39.3
Total	4,775	2.39	114.0	

PRACTICAL APPLICATION

On the basis of these results an ideal system of nitrogenous fertilization would provide during the first month only moderate amounts, not to exceed 20 pounds, of nitrate nitrogen per acre. Any larger amount would not be required by the crop, and would be subject to loss from the soil by leaching as a result of heavy rains. Thereafter rapidly increasing amounts of nitrates should be supplied, to a total of about 120 pounds per acre at the end of the second month. If this amount is materially exceeded, luxury consumption of nitrogen in the final stages of growth may interfere with the normal decline of the nitrogen content in the crop leaves. The tobacco fertilization normally practiced in the Connecticut Valley substantially accomplishes these ends, although nitrates are provided in somewhat excessive amounts during the early growth period. Usually 40 pounds of nitrate nitrogen are applied with the fertilizer, and available nitrogen from organic sources builds up the soil above this level until the beginning of rapid nitrogen intake by the crop. However, nitrogen supply for the season as a whole is apparently well adjusted to the demands of the crop. Although 160 pounds per acre of organic nitrogen are

provided, only about 60 percent of this amount is available during the season, on the basis of data from lysimeter investigations at Windsor.[9]

A duplication of these conditions when using inorganic nitrogen sources is difficult under Connecticut Valley conditions. The application of 120 pounds of nitrogen in such materials at planting time may result in an inadequate supply for normal yield if there is serious leaching from the soil, while, in a season without leaching, larger amounts may prove excessive. Inorganic nitrogen applications may be used in fractional doses, proportional to the demands of the crop during the subsequent period, but in case the soil is dry when these applications are made, they may not diffuse to within reach of the root system in time to be used when they are needed.

It is believed that these data in part explain the general failure of attempts to use large proportions of nitrates or other inorganic sources of nitrogen for the tobacco crop in the Connecticut Valley. They provide a working basis for more intelligent future attempts along this line.

SUMMARY

The rate of growth and of nitrogen intake by the Havana seed tobacco crop was measured for the five seasons, 1929–33. Separate data are presented for the various parts of the plant, including roots, stalks, leaves, and seed pods.

The early growth for the first 30 days after setting was slow, and was followed by a rapidly accelerating increase. Between the thirty-fifth and fifty-fifth day after setting, the crop attained approximately 50 percent of the dry weight attained at harvest time, and extracted from the soil about 60 percent of its total nitrogen requirement.

Topping interrupted normal development, to the extent that the topped plants, even when permitted to grow beyond the normal harvest date to the time of practical maturity of seeds on the untopped plants, failed by more than 1,500 pounds to attain as great a production of dry matter. This difference is primarily due to decreased stalk growth and the prevention of normal terminal seed-pod production. The increased production of sucker leaves on the topped plant was not in excess of the additional production of normal leaves on the untopped plant.

The nitrogen content of leaves attained a maximum about 40 days after setting. The stalk became decreasingly lower in nitrogen content throughout the growth of the crop. The roots increased slightly in nitrogen content for about 30 days, after which they became progressively poorer in nitrogen. The crop leaves lost nitrogen after the plant was topped.

At the time of cutting, tobacco had extracted 114 pounds of nitrogen from the soil, of which 39.3 percent was contained in the crop leaves, 21.5 percent in the sucker leaves, 26 percent in the stalk, and 13.2 percent in the roots.

In order to meet the nitrogen requirements of the crop at various stages of its growth, without providing amounts so greatly in excess of immediate requirements as to be lost from the soil by leaching, a fertilizer should supply not to exceed one-fifth of its nitrogen in the

[9] MORGAN, M. F., STREET, O. E., and JACOBSON, H. G. M. FERTILIZER LOSSES THROUGH LEACHING AS MEASURED BY LYSIMETER EXPERIMENTS. Conn. State Agr. Expt. Sta. Bull. 326: 432–441. 1931.

nitrate form during the first month, and a total of approximately 120 pounds of available nitrogen within 2 months after setting. If the latter amount is greatly exceeded, too much nitrogen may be taken up by the crop during the period immediately prior to cutting, thus causing poor quality due to excessive nitrogen content in the crop leaves. Such a condition is being provided by the present practice of applying 40 pounds of nitrate nitrogen and 160 pounds of organic nitrogen just prior to setting, although this results in a nitrate level in the soil much in excess of immediate requirements for at least a month, and serious losses may occur when heavy rains come during this period. If larger amounts of inorganic nitrogen are to be used in the Connecticut Valley tobacco crop, they should be adjusted to the periodic needs for this element.

THE DIGESTIBLE NUTRIENTS OF NAPIER GRASS AND CROTALARIA INTERMEDIA SILAGES, NATAL GRASS HAY, AND THE DRIED REFUSES OF GRAPEFRUIT AND ORANGE CANNERIES[1]

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INTRODUCTION

In Florida, where tropical and subtropical forage crops are grown, the summer rainy season makes it difficult to cure hay, and consequently increasing amounts of forage are being conserved as silage. Although standard feeds in other parts of the United States have been investigated thoroughly, little appears to be known of the composition and digestibility of a considerable number of forage crops and byproducts now in use in the southeastern part of the country. One type of feed, new in this section, is the dried refuse from the citrus canning plants. There is promise that this byproduct may be an important carbohydrate feed.

This paper presents the results of a study to determine the composition, coefficients of digestibility, and digestible nutrients of silages made from Napier grass (*Pennisetum purpureum* Schum.) and *Crotalaria intermedia* Kotschy, of hay from Natal grass (*Tricholaena rosea* Nees), and of dried refuse from grapefruit and orange canneries.

METHODS

The methods used in conducting the digestion trials were essentially those recommended by Forbes and Grindley.[3] The basal ration consisted of prime cottonseed meal (41 percent total crude protein) and No. 1 Federal grade alfalfa hay. In the experimental rations, one-half of the alfalfa hay was replaced by an equal quantity of the experimental feed, except in the case of silages, where the rate was 3 pounds of silage to 1 pound of hay. In every case, the total ration provided an excess of digestible crude protein above the calculated requirements.

Preliminary feeding periods were 10 days in length, and the experimental periods were from 15 to 20 days. The trials with Napier grass silage totaled 45 "steer-days," and all other trials 80 steer-days each.

[1] Received for publication Apr. 13, 1935; issued September 1935.

[2] The data dealing with *Crotalaria intermedia* were obtained from a cooperative investigation of the feeding value of crotalarias conducted jointly by the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and the Departments of Agronomy and Animal Husbandry of the Florida Agricultural Experiment Station. The digestion trials were conducted by the Department of Animal Husbandry. The silage used was made from forage provided by the Division of Forage Crops and Diseases and the Department of Agronomy. G. E. Ritchey was in charge locally for the Division of Forage Crops and Diseases.

[3] FORBES, E. B., and GRINDLEY, H. S. ON THE FORMULATION OF METHODS OF EXPERIMENTATION IN ANIMAL PRODUCTION. Bull. Natl. Research Council 6, pt. 2, no. 33: 17-27. 1923.

Analyses were made by the methods of the Association of Official Agricultural Chemists.[4] Determinations of nitrogen were made in triplicate on the fresh feces each day in order to avoid losses of nitrogen. All other constituents were determined on 5-day composite samples.

The coefficients of digestibility were obtained by indirect calculation, taking into account the data from the trials with the basal ration for alfalfa hay, and the average coefficients of digestibility given by Henry and Morrison [5] for the grade of cottonseed meal used.

PRESENTATION AND DISCUSSION OF RESULTS

No difficulty was experienced in getting the animals to eat the experimental rations. In general, satisfactory agreement among the results for the different animals and for successive 5-day periods was secured, except in the trials with Napier grass silage. The results for 1 of the 4 animals were discarded in this instance, the other 3 being consistent. The greatest discrepancies appeared in those instances where the intake of the particular feed constituent from the experimental feed was but a small fraction of the total intake of that constituent. However, any error from this source introduced into the calculation of the total digestible nutrient content of a feed is relatively small.

The composition, coefficients of digestibility, and digestible nutrient content of the experimental feeds, together with similar standard feeds for purposes of comparison, are presented in table 1.

The silage from Napier grass, harvested as the heads began to appear, was low in crude protein and high in crude fiber. A high fiber content is presumed to depress the digestibility of forages. This appears to have been the case in this instance, as is seen when the nutrient content of Napier grass silage is compared with that of corn silage, and is most apparent when the nutrients are computed on the dry-matter basis.

Harvest of the *Crotalaria intermedia* was delayed in 1933 by heavy rains, so that the crop became more fibrous than is desirable. The high fiber content of this plant at such a stage of maturity appears to have depressed the digestibility of the nutrients, as is seen in comparisons with soybean silage and alfalfa hay. In common with other legume silages, that of *C. intermedia* contained a greater proportion of crude protein in the dry matter than is present in grasses at a similar stage of maturity.

Even though the harvest of Natal grass must wait until the close of the rainy season, and its growth habits tend toward a higher fiber content, its total digestible nutrients were only slightly below those of timothy hay.

Dried grapefruit and orange cannery refuses were both very palatable to cattle. They had a laxative effect when fed in such quantities that they supplied approximately one-half of the dry matter of the ration. Both of these citrus byproducts were low in protein,

[4] ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS. Compiled by the committee on editing methods of analysis. Revised to July 1, 1924. Ed. 2, 535 p., illus. Washington, D. C. 1925.

[5] HENRY, W. A., and MORRISON, F. B. FEEDS AND FEEDING; A HANDBOOK FOR THE STUDENT AND STOCKMAN. Ed. 18, pp. 709-743, illus. Madison, Wis. 1923.

crude fiber, and fat, but high in digestible nitrogen-free extract. The digestion trials place these feeds in the class of high carbohydrate concentrates.

TABLE 1.—*The percentage composition, coefficients of digestibility, and digestible nutrients of the experimental feeds, as compared with those of similar standard feeds*

Kind of feed	Number of analyses or trials	Dry matter	Crude protein	Crude fiber	Nitrogen-free extract	Crude fat	Ash	Total digestible nutrients	On dry-matter basis	
									Crude protein	Total digestible nutrients
COMPOSITION OF THE FEED										
Napier grass silage	3	32.54	1.17	14.45	14.42	0.68	1.82	.....	.....	.....
Corn silage, well matured [1]	121	26.30	2.10	6.30	15.40	.80	1.70	.....	.....	.....
Crotalaria intermedia silage	4	27.13	3.30	12.52	8.34	.77	2.20	.....	.....	.....
Soybean silage, Florida analyses	23	24.64	2.24	10.03	9.08	.74	2.55	.....	.....	.....
Alfalfa hay [1]	250	91.40	14.90	28.30	37.30	2.30	8.60	.....	.....	.....
Natal grass hay	1	92.24	3.36	39.49	43.12	1.44	4.83	.....	.....	.....
Timothy hay, all analyses [1]	221	88.40	6.20	29.80	45.00	2.50	4.90	.....	.....	.....
Grapefruit refuse, dried	1	91.77	4.94	11.94	69.60	1.06	4.23	.....	.....	.....
Dried orange peel	1	86.04	5.84	10.64	64.74	.69	4.13	.....	.....	.....
Beet pulp, dried [1]	48	91.80	8.90	18.90	59.60	.90	3.50	.....	.....	.....
COEFFICIENTS OF DIGESTIBILITY										
Napier grass silage	3	.....	29.07	50.14	40.19	64.70	.....	.....	.....	.....
Corn silage, well matured [1]	27	.....	51.00	65.00	71.00	82.00	.....	.....	.....	.....
Crotalaria intermedia silage	4	.....	62.87	32.71	40.57	66.92	.....	.....	.....	.....
Soybean silage [2]	4	.....	55.30	42.90	61.20	48.90	.....	.....	.....	.....
Alfalfa hay [1]	109	.....	71.00	43.00	72.00	38.00	.....	.....	.....	.....
Natal grass hay	4	.....	8.16	59.34	51.85	68.64	.....	.....	.....	.....
Timothy hay	58	.....	48.00	50.00	62.00	50.00	.....	.....	.....	.....
Grapefruit refuse, dried	4	.....	24.83	71.52	92.43	79.37	.....	.....	.....	.....
Dried orange peel	4	.....	36.57	93.91	88.51	66.59	.....	.....	.....	.....
Beet pulp, dried [1]	3	.....	52.00	83.00	83.00	.....	.....	.....	.....	.....
DIGESTIBLE NUTRIENTS										
Napier grass silage	.....	.....	0.34	7.25	5.80	0.44	.....	14.38	1.05	44.16
Corn silage, well matured	.....	.....	1.07	4.10	10.93	.66	.....	17.59	4.07	66.88
Crotalaria intermedia silage	.....	.....	2.08	4.10	3.38	.52	.....	10.72	7.66	39.48
Soybean silage	.....	.....	1.24	4.30	5.57	.36	.....	11.92	5.01	48.20
Alfalfa hay	.....	.....	9.09	12.17	26.86	.87	.....	50.08	9.95	54.79
Natal grass hay	.....	.....	.29	23.43	22.36	.99	.....	48.31	.31	52.22
Timothy hay	.....	.....	2.98	14.90	27.90	1.25	.....	48.59	3.37	54.97
Grapefruit refuse, dried	.....	.....	1.23	8.54	64.33	.84	.....	75.99	1.34	82.80
Dried orange peel	.....	.....	2.14	9.99	57.30	.05	.....	69.55	2.49	80.82
Beet pulp, dried	.....	.....	4.63	15.69	49.47	.....	.....	69.79	5.04	76.02

[1] HENRY, W. A., and MORRISON, F. B. See footnote 5.

[2] HOPKINS, C. G. COMPOSITION AND DIGESTIBILITY OF CORN ENSILAGE, COW PEA ENSILAGE, SOJA BEAN ENSILAGE AND CORN-FODDER. Ill. Agr. Expt. Sta. Bull. 43, pp. 181–208. 1896.

SUMMARY AND CONCLUSIONS

The composition, coefficients of digestibility, and digestible nutrients of Napier grass and *Crotalaria intermedia* silages, Natal grass hay, and dried refuse from grapefruit canneries are presented for the first time. Additional data on dried refuse from orange canneries are given.

Napier grass silage is low in digestible protein and contains approximately two-thirds as much total digestible nutrients as does corn silage.

Crotalaria intermedia silage provides less total digestible nutrients than does corn silage, but it is a better source of protein. Cut in an earlier stage of maturity, this silage probably would have been more desirable.

Natal grass hay is comparable with timothy hay in feeding value.

The dried refuses from grapefruit and orange canneries are lower in digestible crude protein, but slightly higher in total digestible nutrients, than is dried beet pulp. These feeds are comparable.

BACTERIAL LEAF SPOT OF ALFALFA[1]

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INTRODUCTION

The bacterial leaf spot described here was first recognized on Turkestan and Grimm alfalfa (*Medicago sativa* L.) in two locations at Madison, Wis., in August 1930. The alfalfa in both instances was in cultivated experimental rows and had been repeatedly splashed by watering with a garden hose. In October 1931 the disease recurred under similar circumstances at one of these locations, but with the abandonment of alfalfa growing at these places the disease has not been seen during the three following summers. At no time has it been found in alfalfa fields. These observations, together with the results of inoculations, suggest that while the disease appears potentially destructive, it does not often find favorable conditions for development in this locality. Inasmuch as it may develop elsewhere and may easily be mistaken for other well-known diseases, its description seems warranted.

DESCRIPTION OF THE LEAF SPOT

This leaf spot, like most bacterial leaf spots, is at first very small and water-soaked in appearance. As the spots increase in size, they may coalesce, especially along the midrib and at the ends of the leaflets, forming areas of dead tissue which soon dries. The dry center of spots attaining a diameter of 2 to 3 mm is often yellow with a dark-brown border surrounded by a straw-colored halo. Smaller lesions may appear merely as dark-brown spots. Characteristic leaf injury from this disease is shown in figure 1. No stem lesions have been observed except following inoculations.

Thus, only in the early stages of its development does the disease suggest its bacterial origin. At that time it is easily distinguished from leaf infections of the bacterial stem blight caused by *Phytomonas medicaginis* (Sack.) Bergey et al. by the absence of the stem lesions characteristic of that disease and also by the small size of the spots, which have not been observed to extend to form the large yellow areas described for that disease. After the early water-soaked condition has passed, this leaf spot resembles certain fungous leaf spots. The smaller dark-brown spots are not easily distinguished from partly developed spots caused by *Pseudopeziza medicaginis* (Lib.) Sacc. The larger bordered spots may closely resemble those caused by

[1] Received for publication Mar. 4, 1935; issued September 1935. Joint contribution of the Wisconsin Agricultural Experiment Station and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. The work was done in part by funds granted from the Civil Works Administration of the Wisconsin Emergency Relief Administration.

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Pseudoplea briosiana (Poll.) Hoehn. Because of the strong resemblance of this bacterial spot to lesions caused by these two fungi, it may have occurred unrecognized many times in the past.

ISOLATIONS AND INOCULATIONS

Six separate isolations of the organism were made in 1930 with the usual poured-plate technic. The pathogenicity of the cultures obtained was proven on plants in the greenhouse, the bacteria were reisolated, and the pathogenicity of the cultures obtained again demonstrated by inoculation.

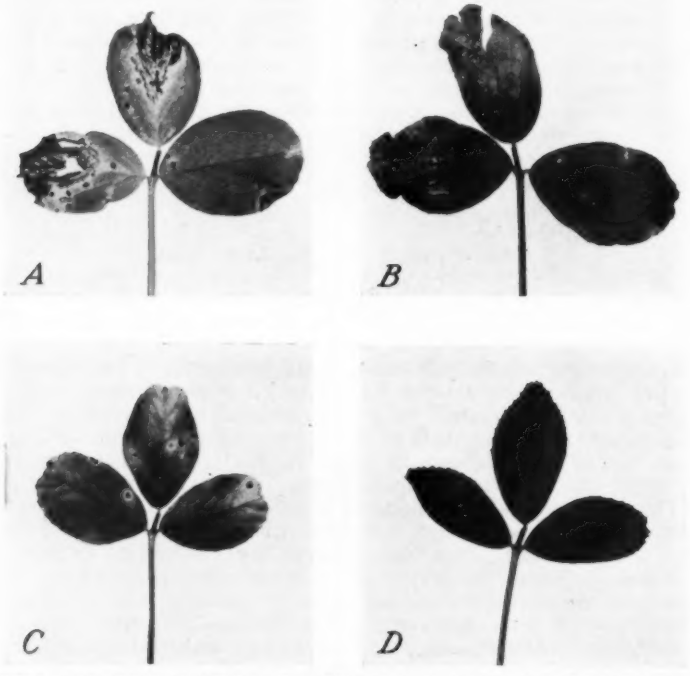

FIGURE 1.—Bacterial leaf spot of alfalfa on diseased leaves from plants growing in a cultivated plot as compared with a healthy leaf: *A* and *B*, Leaves showing extensive injury of leaflets chiefly at the ends and along the midribs; *C*, leaf showing isolated blackened and halo-surrounded spots; *D*, healthy leaf. (About natural size.)

The plants inoculated were kept in a closed glass chamber for half a day before the leaves were sprayed with the bacterial suspension in distilled water, and were left in the chamber for a half day after this inoculation. In some cases a trace of castile soap was added to the bacterial suspension in order to facilitate wetting the leaves. Under these conditions infection was often far more destructive to the plant than natural infection observed in the field. Puncture inoculations

were also made, which, though successful, were not commonly as satisfactory as those made by spraying the leaves.

The cultures were carried in stock until 1933, when their pathogenicity was again demonstrated by greenhouse inoculations. Following this, single-cell isolations were made from the six different cultures.[2] The pathogenicity of these single-cell isolations was demonstrated soon after they were made and again after they had been carried in stock for several months.

BACTERIOLOGICAL STUDIES

The bacteriological characters of these six single-cell cultures were determined according to the common procedures. Unless otherwise noted, the methods employed were those given in current (1933) revisions of publications by the Committee of Bacteriological Technic of the Society of American Bacteriologists.[3] Each of these tests was made in triplicate with suitable controls for each of the six cultures. Unless otherwise noted, each test was performed at least a second and usually a third time.

MORPHOLOGY OF THE ORGANISM

The organisms were all small rods. They were measured [4] from smears of 1-day-old cultures grown on yeast-infusion glucose agar at 22° C. The slides were stained with the negative nigrosine preparation. One hundred organisms were measured from each strain. The average of all was 2.14 μ by 0.45 μ They ranged in length from 0.93 μ to 4.56 μ, and in width from 0.28 μ to 0.77 μ. The organisms were Gram-negative and not acid-fast. No capsules were found after growth for a week on ascitic agar.

Flagella stains with the Caesares-Gil method made on 3 of the 6 strains revealed a single polar flagellum. The other cultures were all observed to be motile in hanging-drop preparations. Some difficulty was experienced in securing motility in these cultures that had been carried in artificial media for a long time.

GROWTH CHARACTERS ON VARIOUS MEDIA

Colony characters determined on nutrient agar after 5 days at room temperature were as follows: Growth, rapid; form, circular; surface, smooth; elevation, convex; edge, entire; internal structure, finely granular; chromogenesis, white to pale yellow; deep colonies, lense-shaped; well-isolated colonies, about 10 to 12 per plate, 7 mm in diameter.

Colony characters determined on plain gelatin after 5 days at room temperature showed the following characters: Growth, rapid; form, circular; edge, erose; liquefaction, cup; internal structure, finely granular. Liquefaction occurred on the fourth day.

Agar strokes on nutrient agar incubated 2 days at room temperature had the following characters: Growth, abundant; form of growth, filiform; elevation, convex; luster, glistening; surface, smooth; odor, absent; chromogenesis, white to pale yellow; consistency, butyrous;

[2] These isolations were made by Dr. J. A. Pinckard.

[3] Society of American Bacteriologists, Committee of Bacteriological Technic. Manual of methods for pure culture study of bacteria. [Looseleaf, See 1933 supplement.] Geneva, N. Y. 1923.

[4] The measurements were made by Mary Jacobson.

medium, unchanged; optical character, translucent. Studies made on 2-percent glucose nutrient agar, 2-percent starch agar, and yeast-infusion glucose agar showed the same characters.

Potato plugs incubated at room temperature for 24 hours showed bacterial characteristics resembling those on nutrient agar. The potato plugs were gray in 72-hour-old cultures.

Stabs in plain gelatin were incubated at room temperature. Liquefaction occurred on the fourth day. On the sixth day, the type of liquefaction was crateriform; and on the tenth day, stratiform.

Growth of the organisms was made in 24 hours in nutrient broth. The medium was slightly cloudy; a small amount of sediment was formed which was viscid on agitation. There was no odor. The same was true of organisms grown in 2-percent glucose broth.

The diastatic action of the organisms was determined on 0.2 percent starch agar. When abundant growth appeared, the plates were flooded with a saturated iodine solution in 50-percent alcohol. Clear zones appeared measuring about 7 mm, indicating diastatic action. This is particularly interesting in relation to the results from sugar fermentation.

Transfers made to litmus milk and kept at room temperature showed the following:

2 days, no color change; 2-mm serum zone.
4 days, no color change; 6-mm serum zone.
7 days, change in color from lavender to tan (with the exception of two organisms, lavender to brown); 15-mm serum zone.
10 days, same color change as on seventh day; 15-mm serum zone.
14 days, entirely clear except for sediment.

Transfers were spread on milk-agar plates (nutrient agar with 1 cc litmus milk) and incubated at room temperature for 2 days. Giant colonies were formed, surrounded by clear zones. These plates were flooded with 10-percent acetic acid. No precipitation occurred in the clear zones, indicating that digestion had taken place.

Nitrate broth was seeded and kept at room temperature. Readings were made after 1, 2, 4, 7, and 10 days for ammonia, nitrites, and nitrates. Growth was obtained in 48 hours. Tests with Nessler's reagent showed the presence of ammonia on the fourth day. More positive reactions for ammonia were obtained on the seventh and tenth days. Tests with Trommsdorf's reagent were negative for nitrites; and tests made with diphenylamine showed that nitrates were still present. Cultures in nitrate broth were uniformly cloudy; sediment formed was viscid on agitation; odor, absent.

Studies were made of sugar fermentation in a yeast-infusion mineral-salt medium with the following composition: Magnesium sulphate ($MgSO_4 . 7H_2O$), 0.2 g; dipotassium phosphate ($K_2HPO_4 . 3H_2O$), 0.2 g; sodium chloride (NaCl), 0.2 g; calcium chloride ($CaCl_2$), 0.1 g; yeast infusion (20 percent), 50 cc; carbon source, 5 g; and distilled water, 950 cc. The reaction was adjusted to pH 6.8. A neutral solution of the carbon source was sterilized separately and added aseptically. The organisms were grown for 7 days at room temperature in this medium, with, respectively, 0.5 percent of pectin, lactose, dextrin, mannitol, sucrose, maltose, glycerin, levulose, salicin, starch, galactose, inulin, and glucose. Determinations of the hydrogen-ion concentration were then made with the common quinhydrone equipment. The results of one representative series of tests appear in

table 1. Some acid was found only with the galactose medium and even this was within the range which carbon dioxide might induce. The reaction commonly became slightly alkaline, doubtless because of utilization by the bacteria of the yeast infusion. The growth developed suggests that the various materials were employed with the formation of relatively neutral products. The action on starch in relation to the action on various sugars is noteworthy. For the purposes of the present study, quantitative measure of sugar utilization and of carbon dioxide production did not appear necessary.

TABLE 1.—*Summary of reactions induced by various single-cell strains of alfalfa leaf spot bacteria incubated 7 days at room temperature in yeast-infusion mineral-salt liquid media containing stated sources of carbon* [1]

Substance tested	Hydrogen-ion concentration from strain no.—						
	1	2	3	4	5	6	Control
d-fructose	7.2	7.0	7.0	7.1	7.1	7.1	6.6
d-galactose	6.5	6.4	6.6	6.3	6.6	6.7	6.7
d-glucose	6.9	6.8	7.0	6.5	6.8	6.7	6.4
Sucrose	7.3	7.4	7.1	7.2	7.2	7.2	6.8
Maltose	7.3	7.3	7.2	7.2	7.3	7.2	7.1
Lactose	7.2	7.1	7.1	7.3	7.3	7.3	6.5
Starch	6.7	6.7	6.7	6.7	6.8	6.7	6.7
Inulin	7.4	7.4	7.3	7.5	7.4	7.4	6.6
Dextrin	7.5	7.2	7.3	7.3	7.3	7.2	7.1
Pectin	7.0	7.0	6.8	7.0	7.1	7.1	6.5
Glycerol	7.2	7.4	7.1	7.3	7.4	7.3	6.6
Mannitol	7.5	7.5	7.5	7.5	7.5	7.5	7.1
Salicin	7.3	7.4	7.3	7.5	7.4	7.4	6.7
None	7.3	7.4	7.4	7.4	7.5	7.6	6.6

[1] There was no growth in the unseeded controls and slight growth in media containing no source of carbon except the yeast infusion. In the starch medium, turbidity appeared only in the upper 10 to 12 mm of the medium. In all other cases relatively dense turbidity and compact sediment, viscid on agitation, indicated good growth. Two other trials gave comparable results.

The suitable temperature for growth was determined with nutrient-agar stroke cultures incubated at the following temperatures: 4°, 8°, 12°, 16°, 20°, 24°, 28°, 32°, and 36° C. These cultures were incubated for 1 week, with the following results: At 4° and 36°, scanty growth; at all other temperatures, abundant growth. In a repetition of the test after incubation for 2 days the results were: No growth at 4°, 8°, and 36°; scant growth at 12° and 16°; and moderate growth at 20°; abundant growth at 24°, 28°, and 32°. In 7 days the results were: No growth at 36°; scant growth at 4° and 8°; abundant growth at 12°, 16°, 20°, 24°, 28°, and 32°. These studies indicate that the most rapid growth of these bacteria on nutrient agar is made between 24° and 32°.

Nutrient-agar shake cultures were used to study the oxygen requirements of the organisms. A suspension of the organism was prepared and three successive loop dilutions of the suspension were made in successive tubes. A small amount of the agar shake cultures from tubes 1, 2, and 3, respectively, was drawn up into different sterile capillary tubes, leaving a clear space at each end which was sealed. Three capillary-tube cultures and three test-tube agar shake cultures with suitable controls were made for each organism and incubated at room temperature. After 10 days colonies showed only in the upper layer of medium in the test tubes; and only at the ends in the capillary tubes, indicating that the organisms are aerobes.

The characters of this alfalfa leaf spot organism do not appear similar to those given in any description found for a bacterial plant pathogen. When compared with *Phytomonas medicaginis*, in addition to the difference in symptoms induced, there appear important bacteriological differences. For example, in contrast with the characters given in this paper, Sackett [5] reported that *P. medicaginis* was doubtful in relation to the Gram stain, made grayish-white growth on agar, did not liquefy gelatin, did not digest starch, did not form ammonia from nitrate, and produced no change in litmus milk except to make it blue.

TECHNICAL DESCRIPTION

This organism is named and briefly characterized as follows:

Phytomonas alfalfae, n. sp.[6]

Organism a rod, average 2.14 μ by 0.45 μ, motile by one flagellum, Gram-negative, not acid-fast, apparently without spores or capsule. On nutrient agar after 5 days at room temperature colony characters were: Growth, rapid; form, circular; surface, smooth; elevation, convex; edge, entire; internal structure, finely granular; chromogenesis, white to pale yellow; well-isloated colonies, 7 mm in diameter; deep colonies, lense-shaped. Gelatin liquefied. Trace of acid formed in yeast-infusion mineral-salts medium with galactose. No change or an alkaline reaction with 12 other sources of carbon. Starch hydrolyzed. Ammonia formed slowly in a nitrate medium. Litmus milk cleared in 2 weeks with digestion of the casein. No growth where atmospheric oxygen was excluded. Growth at temperatures between 4° and 32° C.; most rapid growth between 24° and 32°. Organism causes leaf spots on alfalfa.

SUMMARY

A bacterial leaf spot of alfalfa, apparently new to science, has been observed at Madison, Wis. The symptoms and isolation and inoculation studies are described. On the basis of the morphological and physiological characters of single-cell isolations from six cultures of the organism, it is described as a new species and the name *Phytomonas alfalfae* is suggested.

[5] SACKETT, W. G. A BACTERIAL DISEASE OF ALFALFA. Colo. Agr. Expt. Sta. Bull. 158, 32 pp., illus. 1910.

[6] Synonyms according to other systems of classification in use among plant pathologists are *Pseudomonas alfalfae* and *Bacterium alfalfae*.

CALCIUM CYANAMIDE IN RELATION TO CONTROL OF CLUBROOT OF CABBAGE[1]

By J. C. WALKER, *professor of plant pathology, University of Wisconsin, and agent, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture,* and R. H. LARSON, *assistant in plant pathology, University of Wisconsin*[2]

INTRODUCTION

In a previous publication [3] the writers reported comparative studies of the effect of calcium hydrate ($Ca(OH)_2$), calcium carbonate ($CaCO_3$), and certain other compounds, when applied to infested soil, upon infection of cabbage by the clubroot organism (*Plasmodiophora brassicae* Wor.). It was shown that, in well-watered soil in the greenhouse, infection was reduced perceptibly when the reaction of an acid soil was changed to about pH 7.0, and it was usually inhibited completely at pH 7.2 and above. In the field even heavier applications of $Ca(OH)_2$ and $CaCO_3$ often failed to control the disease although the reaction of the soil was maintained at pH 7.0 or above. When soil was removed from such field plots, however, and tested by growing cabbage plants upon it in the greenhouse, inhibition of the disease was usually complete. The difference between field and greenhouse environments, therefore, appeared to influence the effectiveness of these materials upon clubroot development.

The present paper is a report of a comparative study of $Ca(OH)_2$ and calcium cyanamide ($CaCN_2$) upon clubroot infection. When applied to moist soils $CaCN_2$ undergoes hydrolysis as a result of which $Ca(OH)_2$ and urea ($CO(NH_2)_2$) are formed. Before hydrolysis is complete, the cyanamide anion (CN_2) may be toxic to higher plants. Cyanamide disappears from the soil solution more slowly in some soils than in others, and the factors which influence this change have been studied recently by Fink [4]. In normal soils urea is ammonified rapidly and at this stage a marked increase in alkalinity or decrease in acidity results because two basic substances, $Ca(OH)_2$ and $(NH_4)_2CO_3$, have been produced. When nitrification of the latter takes place, there should be no change in reaction because there is sufficient Ca in the $CaCN_2$ to combine with the nitric acid formed. The extent of the influence of the addition of $CaCN_2$ to a soil on the reaction of that soil will thus depend on soil conditions and the time that has elasped since the addition. In the case of very acid soils, a marked decrease in acidity should result for some time, because the soil acids will combine with the free lime and ammonia as soon as they are

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[2] The authors are indebted to Prof. Emil Truog, Department of Soils, University of Wisconsin, for helpful suggestions.

[3] LARSON, R. H., and WALKER, J. C. SOIL TREATMENT IN RELATION TO CLUBROOT OF CABBAGE. Jour. Agr. Research 48:749–759. 1934.

[4] FINK, D. S. SOIL FACTORS WHICH PREVENT TOXICITY OF CALCIUM CYANAMIDE. Jour. Amer. Soc. Agron. 26: 929–939, illus. 1934.

formed and hold on to the ammonia with considerable tenacity, thus slowing up its further change to nitric acid.

The fact that $CaCN_2$ when applied as a nitrogen fertilizer reduces acidity or increases alkalinity of the soil has led to an interest in its value as a clubroot inhibitor. Both greenhouse and field experiments were carried out to determine its effectiveness on southern Wisconsin soils.

GREENHOUSE EXPERIMENTS

Two series of greenhouse pot tests were conducted. Naturally infested Carrington silty clay loam soil from the Miller farm, Kenosha County, Wis., was used in 2-gallon earthenware crocks. Six kilograms of soil were weighed out for each crock and the desired amount of chemical was thoroughly mixed with the soil. The rates of application are given on the basis of pounds per surface acre; 0.385 g per crock was approximately equal to 100 pounds per acre. Since the cyanamide anion (CN_2) is toxic to plants, it is necessary to delay planting for a sufficient period after the application of $CaCN_2$ to allow complete hydrolysis and the removal of CN_2 from the soil solution. Cabbage (*Brassica oleracea capitata*) seedlings were transplanted to the crocks 2 weeks after treatment. The soil moisture was kept at about 75 percent of the water-holding capacity for 5 weeks, after which period the plants were removed and examined.

In the greenhouse experiments $Ca(OH)_2$ and $CO(NH_2)_2$ were included. The amounts applied were so arranged as to compare a given amount per acre of $CaCN_2$ with (1) the approximate amount of $Ca(OH)_2$ it would yield upon hydrolysis in the soil; (2) the approximate amount of $CO(NH_2)_2$ it would yield; and (3) those amounts of $Ca(OH)_2$ and $CO(NH_2)_2$ applied together. Thus, for example, 125 pounds of $CaCN_2$ yields, when completely hydrolyzed, 87.5 pounds of $Ca(OH)_2$ and 62.5 pounds of $CO(NH_2)_2$.

The results of the first series are given in table 1. The plants in the untreated soil were all infected. As increasing amounts of $Ca(OH)_2$ were added, infection was gradually reduced until none occurred at 525 pounds per acre or more. When $CO(NH_2)_2$ was added at the rate of 125 pounds per acre together with $Ca(OH)_2$ at the rate of 175 pounds, no infection occurred; while in the pots containing $Ca(OH)_2$ at the rate of 175 pounds without urea, 66.7 percent infection occurred. It was evident, therefore, that urea, probably through its rapid conversion to $(NH_4)_2CO_3$, had a decidedly toxic effect upon *Plasmodiophora brassicae*. Urea was not used alone in this series. $CaCN_2$ was competely inhibitive at 250 pounds and above.

In the second series (table 1), smaller applications were included and various amounts of urea alone were used. Again complete inhibition with $Ca(OH)_2$ was not attained below 525 pounds per acre. No infection resulted when 250 pounds per acre or more of $CO(NH_2)_2$ was applied. The pronounced effect of urea is shown when $Ca(OH)_2$ alone and $Ca(OH)_2$ plus urea are compared. $Ca(OH)_2$ at 175 pounds permitted 66.7 percent infected plants; $CO(NH_2)_2$ at 125 pounds permitted 29.2 percent; the two combined in the same respective amounts permitted 20.8 percent i. e., approximately the same amount as urea alone. $Ca(OH)_2$ at 350 pounds allowed 33.3 percent infected plants; $CO(NH_2)_2$ at 250 pounds, no infection; the two applied together resulted in no infection.

TABLE 1.—*The relative effect of calcium hydrate, urea, and calcium cyanamide upon infection of cabbage by Plasmodiophora brassicae when applied to the soil under greenhouse conditions; series 1 and 2*

SERIES 1

Chemical applied	Quantity	Plants tested	Plants diseased	Chemical applied	Quantity	Plants tested	Plants diseased
	Pounds per acre	*Number*	*Percent*		*Pounds per acre*	*Number*	*Percent*
None		60	100	$CO(NH_2)_2$	375	30	0
$Ca(OH)_2$	175	30	66.7	$Ca(OH)_2$	700	30	0
	350	30	23.3	$CO(NH_2)_2$	500		
	525	30	0	$Ca(OH)_2$	1,050	30	0
	700	30	0	$CO(NH_2)_2$	750		
	1,050	30	0	$CaCN_2$	250	30	0
$Ca(OH)_2$	175	30	0		500	30	0
$CO(NH_2)_2$	125				750	30	0
$Ca(OH)_2$	350	30	0		1,000	30	0
$CO(NH_2)_2$	250				1,500	30	0
$Ca(OH)_2$	525	30	0				

SERIES 2

Chemical applied	Quantity	Soil reaction [1]	Plants tested	Plants diseased	Chemical applied	Quantity	Soil reaction [1]	Plants tested	Plants diseased
	Pounds per acre	*pH*	*Number*	*Percent*		*Pounds per acre*	*pH*	*Number*	*Percent*
None		6.4	72	100.0	$Ca(OH)_2$	175.0	6.6	24	20.8
$Ca(OH)_2$	87.5	6.4	24	83.3	$CO(NH_2)_2$	125.0			
	175.0	6.6	24	66.7	$Ca(OH)_2$	350.0	6.8	24	0
	350.0	6.8	24	33.3	$CO(NH_2)_2$	250.0			
	525.0	7.0	24	0	$Ca(OH)_2$	525.0	6.8	24	0
$CO(NH_2)_2$	62.5	6.4	24	58.3	$CO(NH_2)_2$	375.0			
	125.0	6.6	24	29.2	$Ca(OH)_2$	1,050.0	7.2	24	0
	250.0	6.8	24	0	$CO(NH_2)_2$	750.0			
	375.0	6.8	24	0	$CaCN_2$	125.0	6.7	24	12.5
	1,000.0	7.2	24	0		250.0	6.8	24	0
$Ca(OH)_2$	87.5	6.6	24	62.5		500.0	7.1	24	0
$CO(NH_2)_2$	62.5					750.0	7.3	24	0

[1] At the close of the experiment.

The next point of interest is the comparison of $CaCN_2$ with the combined effect of its products of hydrolysis, $Ca(OH)_2$ and $CO(NH_2)_2$. It has been pointed out that before hydrolysis is complete the CN_2 anion is toxic to higher plants. Nothing is known of its toxicity to the clubroot organism, but it may be expected that some reduction in the infestation might occur because of the presence of CN_2 before complete hydrolysis. That such is the case is indicated in the results. $CaCN_2$ at 125 pounds reduced infection to 12.5 percent, while the proportionate amounts of $Ca(OH)_2$ (87.5 pounds) and $CO(NH_2)_2$ (62.5 pounds) applied together reduced it to only 62.5 percent. $CaCN_2$ at 250 pounds reduced infection to nil, while the proportionate amounts of $Ca(OH)_2$ (175 pounds) and $CO(NH_2)_2$ (125 pounds) applied together, permitted 20.8 percent infection.

It is indicated in these experiments that $CaCN_2$ is approximately equal to urea and about twice as effective as $Ca(OH)_2$ in controlling clubroot. Specifically, 250 pounds of $CaCN_2$, 250 pounds of $CO(NH_2)_2$, and 525 pounds of $Ca(OH)_2$ each completely inhibited infection.

FIELD EXPERIMENTS

Field trials were conducted in 1933 and 1934 at Franksville, Wis., and on the Miller farm near Somers. The soil at both of the locations has been previously described.[5]

The first series at the Franksville field (referred to as series 1) was on part of the plot used in former experiments. A portion of this area had received 2½ tons of $Ca(OH)_2$ in the autumn of 1930, but little or no control of clubroot was secured in the following year. The entire area received an application of 220 pounds of $CaCN_2$ per acre in November 1932. It was divided into nine parts, each 9 rods by 1 rod in dimension. To certain of these nine plots $CaCN_2$ was applied on May 24, 1933. To other plots $Ca(OH)_2$ was applied on June 26, 1933. In this and subsequent field experiments the materials were incorporated into the soil by very thorough disking immediately following application. The soil was disked and dragged again just before transplanting. The entire area was planted on July 11. No fertilizer other than $CaCN_2$ was applied. On September 28, plants were pulled and the amount of clubroot recorded. The same area was planted in 1934 without any further addition of lime or cyanamide. The results are given in table 2.

TABLE 2.—*The effect of various amounts of calcium hydrate and calcium cyanamide on clubroot infection in the field; Franksville series 1*

Chemical applied	Quantity	1933 results			1934 results		
		Soil reaction[1]	Plants examined	Plants diseased	Soil reaction[1]	Plants examined	Plants diseased
	Pounds per acre	*pH*	*Number*	*Percent*	*pH*	*Number*	*Percent*
None		6.2	170	79.4	6.8	100	55
$CaCN_2$	220	6.2	167	64.1	6.5	100	94
	440	6.2	183	63.9	6.5	100	88
	[2] 440	6.6	151	21.2	7.2	100	34
	880	6.3	174	86.2	6.6	100	56
	[2] 880	6.2	150	8.0	7.2	111	27
$Ca(OH)_2$	[2] 2,000	6.4	158	22.2	7.0	100	28
	3,000	6.8	171	24.6	7.0	100	51
	4,000	7.0	185	16.8	8.0	100	18

[1] At the end of the growing season.
[2] These plots had received an application of 2½ tons of $Ca(OH)_2$ in the fall of 1930.

As pointed out earlier [5] with $Ca(OH)_2$, the behavior of neutralizing substances as clubroot inhibitors in the greenhouse is no indication of their success in the field. The untreated soil in this series was essentially the same in reaction as that used in the greenhouse experiments. Five hundred and twenty-five pounds of $Ca(OH)_2$ per acre was sufficient to completely check clubroot in the greenhouse, but 4,000 pounds in the field still permitted some infection. Two hundred and fifty pounds per acre of $CaCN_2$ in the greenhouse prevented infection, but 880 pounds in the field did not inhibit the parasite completely.

$Ca(OH)_2$ at the rate of 4,000 pounds per acre gave good control in 1933 and in 1934. Three thousand pounds reduced infection fairly well in 1933, but this plot showed a decided increase in infection in 1934. Control on the 2,000-pound plot was nearly as good as on the

[5] LARSON, R. H., and WALKER, J. C. See footnote 3.

4,000-pound plot, but the former had received an application of $Ca(OH)_2$ in 1930.

$CaCN_2$ was commercially effective only in the 440- and 880-pound applications on plots where $Ca(OH)_2$ had been applied in 1930. Where lime had not been applied previously, the $CaCN_2$ plots showed high percentages of clubroot infection in both 1933 and 1934.

In 1934, 22 plots, 2 by 3 rods in dimension, were laid out in the Franksville field (series 2). They are listed in table 3 in their order of position, and the type of treatment in each is indicated. The soil reaction in each plot was determined before any treatment was made and again after the crop was harvested. $CaCN_2$ and $Ca(OH)_2$ were applied on May 4. At the time of planting, on June 21, 0–9–27 fertilizer was applied in the row at the rate of 300 pounds per acre. Favorable weather prevailed immediately after transplanting, but the following 2 months were decidedly deficient in rainfall. Growth was therefore very slow and the midseason variety used, Marion Market, produced small heads. After harvest (Sept. 11) 100 plants in each plot were pulled and examined for the occurrence of the disease on the roots.

TABLE 3.—*The effect of various amounts of calcium hydrate and calcium cyanamide on clubroot infection in the field; Franksville series 2, 1934*

INDIVIDUAL PLOTS

Plot no.	Chemical applied	Quantity	Soil reaction		Clubroot-infected plants	Yield per acre
			Before application	After harvest		
		Pounds per acre	*pH*	*pH*	*Percent*	*Tons*
1	None		6.2	6.2	69	4.0
2	$Ca(OH)_2$	1,500	6.2	7.4	36	4.0
3	$CaCN_2$	200	6.2	6.5	32	4.1
4	None		6.1	6.2	50	4.1
5	$CaCN_2$	400	6.2	7.0	66	5.3
6	do	800	6.8	7.4	58	5.1
7	None		7.0	6.8	64	5.5
8	$Ca(OH)_2$	1,500	5.9	7.6	59	5.2
9	$CaCN_2$	200	6.2	6.8	55	4.5
10	None		6.3	6.2	72	5.9
11	$CaCN_2$	400	6.2	6.7	44	6.7
12	do	800	6.1	7.2	29	5.5
13	None		6.1	6.2	54	5.1
14	$Ca(OH)_2$	1,500	6.1	7.6	50	5.5
15	$CaCN_2$	200	6.8	6.7	74	7.1
16	None		6.6	6.6	80	5.7
17	$CaCN_2$	400	6.3	7.0	57	4.8
18	do	800	6.1	7.2	32	4.4
19	$Ca(OH)_2$	1,500	5.9	7.8	42	5.5
20	$CaCN_2$	200	6.2	6.7	76	4.8
21	None		6.8	6.5	55	4.0
22	$CaCN_2$	400	6.1	6.8	65	4.0

AVERAGES FOR NUMBER OF PLOTS INDICATED

7	None		6.4	6.4	63.4	4.90
4	$Ca(OH)_2$	1,500	6.3	7.6	46.8	5.05
4	$CaCN_2$	200	6.4	6.7	59.3	5.13
4	do	400	6.2	6.9	58.0	5.20
3	do	800	6.3	7.3	39.7	5.00

Clubroot was by no means held in check completely in any of the plots. There was considerable variation between duplicate plots of the same treatment. The untreated plots varied from 50 to 80

percent in the number of diseased plants; the $Ca(OH)_2$ treatment varied from 36 to 59 percent; the 200-pound $CaCN_2$ treatment from 32 to 76 percent; the 400-pound $CaCN_2$ treatment from 44 to 66 percent; and the 800-pound $CaCN_2$ treatment from 29 to 58 percent. The variability rather detracts from the value of the differences between the averages for each treatment. Certainly there is no significant difference between the 200- and 400-pound treatments of $CaCN_2$ and the control. The hydrate treatment and the 800-pound cyanamid treatment changed the soil reaction to alkaline and seem to have reduced infection distinctly although not by any means completely.

The yields from the various plots show no consistently significant differences between treatments. This may be due in part to the poor conditions for growth.

The third trial in 1934 was on the Miller farm. Plots were laid out in a portion of the field which was known to have shown clubroot when it last grew cabbage several years before (about 1930). At that time it had received an application of 1,000 pounds of $Ca(OH)_2$ per acre. In the fall of 1933, 20 loads of manure per acre were applied. $CaCN_2$ was applied on May 12 and disked in thoroughly. At the time of planting, on July 10, 125 pounds of 3–12–12 fertilizer per acre were applied in the row. Wisconsin All Seasons, a late yellows-resistant sauerkraut variety, was used.

As a result of the low rainfall in July and August, growth was very slow. During September and October precipitation was fairly abundant. The remainder of the growing season, however, was not long enough and at harvest on October 31 many heads were still soft and immature. On this date a 6-rod strip in the central three rows of each plot was harvested and weighed. Fifty plants in each were pulled and examined for disease. In table 4 the order of the plots in the field is maintained. The reaction of the soil originally was about the same as that of the Franksville soil. The 825-pound treatment was the only one which brought the soil to neutrality. There is rather conclusive evidence here that the two heaviest treatments reduced clubroot infection materially. As at Franksville, however, there was no measurable benefit of calcium cyanamide in increasing yield.

TABLE 4.—*The effect of various amounts of calcium cyanamide on clubroot infection in the field; Miller series, 1934*

Plot no.	Rate of $CaCn_2$ application	Soil reaction		Club-root infected plants	Yield per acre	Plot no.	Rate of $CaCn_2$ application	Soil reaction		Club-root infected plants	Yield per acre
		Before application	After harvest					Before application	After harvest		
	Pounds per acre	*pH*	*pH*	*Percent*	*Tons*		*Pounds per acre*	*pH*	*pH*	*Percent*	*Tons*
1	None	6.1	6.2	62	7.4	5	None	6.0	6.2	30	14.2
2	200	6.3	6.5	44	11.5	6	825	6.1	7.0	6	12.7
3	None	6.2	6.3	56	13.7	7	None	6.1	6.2	65	8.8
4	400	6.0	6.7	14	15.9						

DISCUSSION

The potential value of $CaCN_2$ in the control of clubroot can be estimated best from the greenhouse pot tests since the conditions

under which they were conducted probably approach the optimum both for the activity of the parasite and for hydrolysis of the chemical. In these tests $CaCN_2$ at the rate of 125 pounds per acre was somewhat more effective than $Ca(OH)_2$ at the rate of 350 pounds per acre. $CaCN_2$ at 250 pounds completely inhibited infection, while this degree of control by $Ca(OH)_2$ was not reached until 525 pounds per acre was applied.

A given amount of $CaCN_2$ was decidedly more effective than the corresponding amounts of $Ca(OH)_2$ and $CO(NH_2)_2$ derived from its hydrolysis. This fact suggests that $CaCN_2$ affects the clubroot organism not only through the basic substances formed from it but also through the toxic effect of the CN_2 anion in the soil solution before hydrolysis is complete.

Under field conditions in southern Wisconsin in 1933 and 1934 much heavier applications of $CaCN_2$ and of $Ca(OH)_2$ did not completely control clubroot even though the materials were worked into the soil quite thoroughly. As earlier pointed out in comparative greenhouse and field experiments with $Ca(OH)_2$, field environment appears to influence greatly the effectiveness of $CaCN_2$ as a clubroot inhibitor. Where $Ca(OH)_2$ had been applied to the soil 3 or 4 years previously, 400 to 800 pounds of $CaCN_2$ per acre was fairly effective (Franksville series 1 and Miller series), although complete control was not attained. The results show, however, that $CaCN_2$ has some value and from the limited results obtained in the field and greenhouse it appears to be about twice as effective pound for pound as $Ca(OH)_2$. Where a nitrogen fertilizer is needed, it can be used together with lime as a corrective for soil acidity with the expectation that conditions for clubroot infection will be made less favorable, and the completeness of control will be influenced by the soil environment.

SUMMARY

A study was made of the influence upon cabbage-root infection of $CaCN_2$ when applied to clubroot-infested soil.

In greenhouse tests with soil having a reaction of pH6.4, $CaCN_2$ at the rate of 250 pounds per acre prevented infection while 525 pounds of $Ca(OH)_2$ was required to accomplish the same effect.

When $CaCN_2$ was compared with corresponding amounts of $Ca(OH)_2$ and $CO(NH_2)_2$ resulting from its hydrolysis, the fungicidal value of $CaCN_2$ was greater, indicating that its toxicity is due not only to the basic substances formed from it, but also to the CN_2 anions in the soil solution before hydrolysis is complete.

Much higher quantities of $CaCN_2$ were required to reduce infection in the field than in the greenhouse, which is similar to results secured with $Ca(OH)_2$ earlier and in this series of experiments. This difference is interpreted as due to the influence of soil environment upon the effectiveness of both of these chemicals.

The results in the greenhouse and in the field indicate that $CaCN_2$ is roughly about twice as effective, pound for pound, as $Ca(OH)_2$ in reducing the amount of clubroot infection.

In cases where soil acidity needs to be corrected in order to reduce clubroot infection, $CaCN_2$ can be used up to the point where the need for available nitrogen is satisfied. If a still larger amount of a neutralizing element is required, $Ca(OH)_2$ should be used to supplement the cyanamide.

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